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MAINTENANCE ENERGY REQUIREMENTS OF BEEF COWS

BY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Maintenance energy requirements of beef cows" submitted by Walter Dietz, B.Sc. (Ag.) in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

A study was conducted to assess the winter maintenance energy requirements of pregnant beef cows similar in skeletal body size but differing in weight due to differences in body condition. Cows at three levels of body conditions, Fat, Medium and Thin, were used in the experiment. One group of cows at each level of body condition was fed to maintain that level throughout the experiment (Fat, Medium and Thin groups). In addition one group of fat cows (Fat/Thin) was fed so as to lose weight and one group of thin cows (Thin/Fat) was fed so as to gain weight following the onset of cold winter climate and throughout the remainder of the experiment.

Measurements of weekly weight and feed intake were made to determine the daily metabolizable energy required to maintain a constant body weight. Other measurements of body insulation and blood constituents were made to assess adaptation to cold and metabolic stress.

Ambient temperature and wind at the experimental site were recorded daily.

It was found the energy required for maintenance was directly related to body weight and cold stress. The energy requirements per unit of metabolic weight were similar for cows in fat and thin body condition. The mean values of the groups of cows over the winter, ranged from 132 to 156 Kcal of ME/Kg$^{3/4}$/24 hour. These values are comparable to other values reported in the literature.

Cold ambient temperatures gave rise to greater increases in energy requirements for thin than for fat cows. However, the absolute energy requirements of thin cows of comparable body skeletal

size did not exceed the requirements of fat cows.

Fat cows, offered feed at a level sufficient to maintain weights of thin cows (Fat/Thin group) utilized body tissue to meet their energy requirements. Such cows were not as sensitive to cold, as indicated by weight changes, as are the thin cows at the same level of feed intake.

The levels of glucose, free fatty acids and ketone bodies in plasma, as indices of energy metabolism, indicated there was not any severe metabolic stress at any of the sampling times during the experiment.

It was concluded that fat cows had a greater total energy requirement for maintenance than thin cows of similar skeletal body size. The greater energy requirement of the fat cows can therefore be attributed to the cost of maintaining greater tissue mass.

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INTRODUCTION

The cost of feed required to keep the brood cow herd over the winter is a major cost to the beef industry. Furthermore, the winter feeding period in cold regions, such as Alberta, extends over several months of the year. It is, therefore, of considerable advantage to the industry to be able to feed cows at a minimum level but still maintain satisfactory performance.

The scientific definition of the maintenance energy requirement of an animal is the minimum level of energy intake that will maintain the animal in a constant energy balance, that is, when the total energy intake is equal to the energy utilized for physiological processes and combating environmental stresses. This requirement varies with the liveweight of the animal, physiological functions, activity, the environmental stresses and the individual ability of animals to combat the stresses.

It is usual, in cold regions where cattle are produced, for fetal development to be taking place when the cow is subjected to the greatest climatic stress of the year, that of cold. Any additional energy required for pregnancy must then be obtained by the cow in the form of extra feed or from mobilizing her body fat energy reserves. Subcutaneous fat deposits, as well as being a source of energy, can act as an insulator against loss of heat energy to a cold environment. These advantages of storing depot fat are partially offset by an energy expenditure for maintaining body fat.

It is well known that animals of different weights have different energy requirements for maintenance (Brody 1945, Kleiber 1961). It is not established whether this difference in maintenance requirements

also applies to animals that differ in liveweight simply as a consequence of differences in body condition. Body condition is a term used to describe the amount of reserve depot fat stored in the body particularly in the subcutaneous tissues.

The main purpose of the present study was to evaluate the maintenance energy requirements of pregnant beef cows, kept at different levels of body condition over the winter in a cold region of Canada, where the beef cattle industry is of major economic importance. As well as determining the energy required for maintenance of the cows, other measurements such as the concentrations of various blood constituents were taken. These biochemical parameters were used to indicate metabolic stress due to climatic conditions and/or undernourishment.

REVIEW OF LITERATURE

I. RECOMMENDED FEEDING STANDARDS

Feeding standards have been readily available throughout many parts of the world for many years. Those in most common use in North America are published by the National Academy of Sciences (NRC 1963, 1970) and are referred to as the National Research Council (NRC) recommended nutrient requirements. The NRC recommendations will be used as the basis for consideration in this thesis.

The digestible energy (DE) requirements for wintering pregnant cows recommended by NRC in 1963 were based upon feeding trial data which show 0 to 0.18 kg daily gain on computed DE intakes of 18 to 22 Mcal daily for cows weighing 454 kg (1000 lbs) to 544 kg (1200 lbs) (NRC 1963). From this, it was determined 18 Mcal of ME is the daily energy requirement for wintering mature pregnant cows in this weight range when daily gains are expected to be 0 to 0.18 kg per cow. The NRC recommended requirements were revised in 1970 and show about a 17 per cent lower requirement for a 450 kg cow, than those recommended in 1963 (NRC 1970). No detailed reason was given for the revision.

Several experiments were conducted to test the NRC (1963) listed energy requirements for wintering mature pregnant cows. Jordan et al (1968a) stated that cows provided with energy at the listed level, become excessively fat under conditions prevalent in Eastern Canada and that this can result in parturition paresis and acetonaemia. Under southeastern Alberta conditions Hironaka and Peters (1969) found that cows fed at 96 per cent of the NRC (1963) listed requirements in one winter, gained weight. However they found in two subsequent winters, energy levels of 106 and 103 per cent of the NRC (1963) listed

requirements resulted in liveweight losses. Wiltbank et al (1962) at Nebraska showed that mature cows fed at the equivalent of 100 per cent of the NRC (1963) listed requirements prior to calving, gained weight and maintained body condition. Cows at 50 per cent of that level lost liveweight and body condition. As yet there are not any reports of the 1970 NRC revised requirements being tested. The NRC (1963 and 1970) listed requirements have proved to be useful guides under practical conditions but adjustments may need to be made for local conditions.

Measurements of the energy requirement for a pregnant cow are based on the definition that the maintenance energy requirement is the dietary energy intake required to maintain an energy equilibrium in the body. That is, the dietary energy intake is equal to the energy lost from the body so that the energy retention is zero. Technical difficulties often preclude an accurate measurement of energy equilibrium and it is generally assumed that a constant body weight represents a constant energy status. Possible consequences of using this assumption will be discussed later. A more practical definition of the maintenance energy requirement of beef cows may be the energy level required to produce a satisfactory level of reproduction. Since the main interest in keeping a brood cow is to have her produce a calf regularly, then the energy required by the cow to maintain a prescribed level of reproduction is the maintenance energy requirement. A biochemical approach to obtain estimates may be the dietary energy required to maintain a prescribed nutritional status as indicated by biochemical parameters.

The methods used to determine the maintenance energy requirements,

in view of the above definitions, are discussed below.

II. METHODS OF DETERMINING ENERGY REQUIREMENTS

1. Direct and Indirect Calorimetry

Direct and indirect calorimetry have been used extensively for laboratory studies of energy expenditure which have been the basis of much of the knowledge on energy requirements of livestock. Because of the nature of the measuring apparatus, calorimetric methods have generally not been used for field measurements. Exception to this has been a couple of recent developments which have found limited application under practical conditions. The mobile indirect calorimeter of Corbett et al (1967) and the carbon dioxide entry rate technique of Young et al (1967) made it possible to measure energy expenditure of grazing sheep, and recently the carbon dioxide entry rate technique has been adapted to measure the energy expenditure of freely grazing cattle (Young 1970). While these new calorimetric techniques open new areas for study of the energetics of animals in their normal habitat they are not as yet developed to the stage where they will function under freezing conditions. These techniques were therefore not considered further for the present study as freezing conditions were expected.

2. Comparative Slaughter Technique

The comparative slaughter technique has been used by Garrett et al (1959) and Garrett (1970, 1971) to estimate maintenance energy requirements. This technique involves the measurement of the feed intake of animals over an extended period and an estimation of the changes in energy content of the animals over the period. Changes in energy

content are estimated by slaughtering groups of animals at the start and end of the period and analyzing the carcasses for energy content. Feed intakes are then adjusted for changes in caloric content of the weight gains to determine the energy required to keep the energy content of the body constant.

This technique has been effectively used to compare the energy requirements of sheep and cattle during the growing and fattening periods (Garrett et al 1959). It has been possible with this technique to show differences in chemical composition of gains and in the efficiency of energy utilization of different types of rations (Orskov and McDonald 1970). It has also been recently used to determine the effect of sex on energy requirements in cattle (Garrett 1970).

No reports have been found of the comparative slaughter method being used with pregnant cows. The technique was of limited use in the present study because of the large numbers of cows required and the need to destroy them to obtain the desired measurements.

3. Feed Intake for Constant Weight

The most usual method used to obtain estimates of maintenance energy requirements of animals under field conditions has been from estimates of feed intake required to maintain animals at a constant weight (Wallace 1956, Adler et al 1960, Corbett 1960, Lambourne and Reardon 1963, Langlands et al 1963a, 1963b, Young and Berg 1970). This method usually involves feeding animals at a number of different levels of energy intake above and below maintenance, and by interpolation determining the level of intake required to keep body weight constant. This method is, however, subject to error in the

interpretation when constant weight is used as an indication of zero energy retention. A measured change in body weight of an animal may not be a true reflection of the energy retention due to possible changes in the chemical composition of the body (Garrett et al 1959, Garrett 1970, 1971). This may be particularly true in the pregnant cow which has a growing fetus and the implications for the present study are discussed in more detail later. However, the method is practical and can be used in field studies.

The above method was used by Young and Berg (1970) to estimate the energy intake required to maintain the weight of beef cows and the energy involved to produce a unit of gain or loss in weight. They found that to achieve a gain or loss of 1 kg of body weight per day, it was necessary to add or subtract, respectively, 5.17 Mcal of ME from the maintenance ration.

4. Satisfactory Reproductive Performance

Maintenance energy requirements have been assessed by studying the effects of different levels of energy intake on several reproductive traits. The effects of different levels of energy intake, by cows during pregnancy, on the weights of the calves, at and following birth (Wallace and Raleigh 1964, Hironaka and Peters 1969), as well as on the skeletal size of the calves (Jordan et al 1968b), have been studied. Wiltbank et al (1962) and Gardner (1969b) determined the effects of prepartum energy intake levels on traits important in rebreeding performance of the cows, such as the time to involution of the uterus, time to estrus, and conception rates. From the results, the authors were able to determine the level of dietary energy intake

required for a satisfactory reproductive performance. This is a practical approach to maintenance energy requirements, since the beef cow is maintained for reproductive purposes.

5. Use of Biochemical Parameters

Free fatty acid (FFA) concentrations in blood plasma were successfully used by Russel et al (1967a, 1967b) as an index to maintain a moderate level of undernourishment in pregnant ewes. As pregnancy advanced, the ewes dietary intakes were individually adjusted weekly to maintain a prescribed nutritional status regardless of whether the ewe was carrying a single or twin fetus. This was possible because the inadequacy of energy intake is readily detected by changes in FFA levels in plasma (Annison 1960). Immediate increases in FFA levels in sheep were found by Reid and Hinks (1962c) when the ration was reduced 40 per cent. The fact that milking cows had a higher requirement for energy than dry cows was reflected by higher levels of FFA in the plasma of the milking cows, in both fed and fasted conditions (Radloff et al 1966). Holmes and Lambourne (1970) found FFA levels in plasma of cattle varied inversely with DE intake.

A similar procedure was applied to the use of ketone bodies to maintain a level of severe undernourishment in pregnant ewes (Russel et al 1967a, 1967b) and to adjust feed intakes to prevent ketosis (Reid and Hinks 1962a). The predetermined levels of ketone bodies to be maintained were 8-10 mg per 100 ml of plasma for severe undernourishment, and less than 2 mg of acetone per 100 ml of plasma to prevent ketosis.

The concentrations of FFA were found to be a more sensitive

criterion of moderate undernourishment during pregnancy than ketone bodies (Russel et al 1967a, Reid and Hinks 1962b) but ketones are a more useful indicator of severe undernourishment at which time FFA levels are at or near maximum levels (Russel et al 1967a). Ketone bodies can originate from ketogenic volatile fatty acids of rumen fermentation as well as from FFA released from depot fat (Adler et al 1963). Under fasting conditions, FFA are the primary source of ketone bodies (Radloff et al 1966).

Reid and Hinks (1962a) conclude that the use of blood ketone levels as a criterion of inadequate nutrition, underestimates additional feed requirements for maintenance, because the fat pregnant ewe when undernourished is better able to maintain blood glucose and ketones in the normal range than the ewe in medium body condition.

Russel et al (1967a, 1967b) found the energy requirements of pregnant ewes increased with increased weight of the fetus. The changes in the concentration levels of FFA, ketones and glucose in blood plasma of ewes are also dependent on the weight of the fetus (Reid and Hinks 1962a, 1962b, Karihaloo et al 1970). Thus FFA and ketones appear to be useful indicators of metabolic stress and could be used to determine maintenance energy requirements of cows.

III. BODY COMPOSITION AND MAINTENANCE

Body weight change may not be a true indicator of the energy balance in pregnant cows because of possible differences in the chemical composition. Body tissues do not remain static but rather are in a dynamic state. Degradation and resynthesis of body tissues are continuous processes (Brody 1945). When a constant weight is

used as the criterion for determining maintenance energy requirements, it is implied that the rate of degradation of a tissue is equal to the rate of its resynthesis, or the degradation of one tissue is accompanied by a concomitant synthesis of another tissue of equivalent weight. The chemical composition of synthesized tissue may not be the same as that degraded. This has particular significance when pregnancy is involved.

The chemical composition and calorific value of a developing conceptus changes with the stage of pregnancy. The data from Langlands and Sutherland (1968) shows that the proportion of fat in the gravid uterus increases and water decreases with advancing pregnancy. The daily rate of fat and protein deposition were similar. The results reported by Orskov and McDonald (1970), Thorbeck (1970), Petersen (1970) and Kielanowski and Kotarbinska (1970) showed that the energy required to deposit one gram of protein or one gram of fat in an animal was about 13 Kcal of ME. This is the total amount of energy expended in the process of synthesis of protein or fat in body tissue. It is well known that the heat of combustion of a gram of fat is higher than that of a gram of protein (Blaxter 1962). It is reasonable, therefore, to deduct that the energy required to deposit 1 Kcal of energy as fat would be lower than to deposit 1 Kcal of energy in the form of protein (Orskov and McDonald 1970, Thorbeck 1970, Petersen 1970, Kielanowski and Kotarbinska 1970). Thus, any difference in the energy required per unit of gain or loss in weight when the chemical composition differs is due to the difference in calorific value of the tissue mobilized or deposited.

The calorific value of the gravid uterus at term in ewes was

found by Langlands and Sutherland (1968) and Graham (1964) to be 0.94 and 0.87 Kcal per gram respectively. These values are much lower than those of the lamb at birth (Graham 1964) or of liveweight gains of growing and fattening sheep and cattle (Garrett et al 1959, Garrett 1970, 1971). If weight is kept constant during pregnancy, it seems that this would involve utilizing maternal body tissues at a rate comparable to the gain in weight of the conceptus. If the calorific values suggested above are extrapolated to pregnant cows kept at a constant weight, then the calorific value of the maternal tissue utilized or degraded is much higher than the tissue synthesized in the conceptus. Thus, a pregnant cow maintained at constant weight would have to be in a negative energy balance.

The calorific value of gains or losses in weight dictate the extent of positive or negative energy balance. Pregnant cows with weight gains comparable in calorific value to that of growing animals, would indicate that the gain was due to a combination of increase in the weight of the conceptus and some maternal tissue deposition. The value of 5.17 Mcal of ME per kg of gain or loss in weight in pregnant cows derived by Young and Berg (1970) is comparable to the value of 5.13 Mcal of ME per kg of gain in younger heifers in the first 98 days of feeding derived by Garrett (1970). This value of 5.17 Mcal per kg of gain or loss in weight for pregnant cows might be expected to be unrealistic if fat deposition is markedly greater than occurred under the conditions in which the value was determined. Garrett (1970) found that heifers required 6.70 Kcal/g of gain in the last 98 days of 294 days of feeding when the proportion of fat in the gains was about twice, and the protein one half as much as in the first 98 days

of the feeding period.

It is apparent that weight changes must be interpreted on the basis of caloric content when these are used in determining maintenance energy requirements.

IV. PARTITION OF WINTER ENERGY REQUIREMENTS OF PREGNANT COWS

The winter energy requirements of a mature pregnant cow can be partitioned, for the purpose of the present study, into categories according to the energy required for several body functions. The following five categories will be discussed.

1. Basal metabolism
2. Muscular activity
3. Heat increment of food utilization
4. Pregnancy
5. Cold stress

1. Basal Metabolism

Basal metabolism is the minimum energy that must be expended to keep the physiological processes, essential to maintaining life, functioning. Any increase in this rate of energy expenditure is then due to increased metabolism as a consequence of such normal life processes as the ingestion of food, muscular activity, pregnancy or combating the stresses of the environment or disease (Brody 1945, Blaxter 1962, Guyton 1966). Thus, basal metabolism is a convenient starting point to measure the energy required for various body functions (Brody 1945, Blaxter 1962). In ruminant animals, the basal or minimal rate of energy expenditure is difficult to measure because of technical reasons, so it is more usual to determine the Fasting Metabolic Rate (FMR) (Forbes et al 1931). FMR in the ruminant is measured when the animal is in a state of minimal muscular activity,

in a thermoneutral environment, and in a post absorptive state following several days of fasting. FMR is measured over fairly long periods of time and is generally considered to be greater than the basal metabolic rate (Blaxter 1962).

2. Muscular Activity

Energy is expended in the process of muscle contraction (Guyton 1966). For two steers, Forbes et al (1931) estimated that the mere act of standing required 46 and 66 more calories per hour than lying down during a measurement of FMR. A more detailed study was reported recently by Colovos et al (1970). They found 16.2 Kcal/kg$^{0.75}$/24 hr more energy was required by steers for standing than for lying. The energy expended in changing positions was significantly ($P \leq 0.01$) larger than that required to maintain a standing or lying posture.

Young (1966) observed differences in the energy required by sheep for eating rations differing in bulkiness. He estimated grazing costs of 6.0 cal/g of pasture consumed compared with 1.66 cal for each g of timothy hay. Langlands et al (1963b) found grazing sheep required 24 per cent more digestible organic matter for maintenance than did similar sheep housed. These findings indicate additional energy is expended in the muscular activity involved in standing, eating different rations and in the process of gathering food by grazing.

By walking sheep on the level and on gradients, Clapperton (1964) noted the energy expenditure of walking was greater than for standing. The energy expenditure increased with the speed of walking. Raising the body a vertical distance required more energy than walking horizontally and did not change significantly with a change in gradient.

The energy expenditure for maintenance, therefore, can be markedly affected by factors that influence the muscular activity of a cow.

3. Heat Increment of Food Utilization

The heat increment of food utilization is the additional energy that is expended by the animal for metabolic processes required to utilize ingested nutrients. This was stated by Kleiber (1961) as the difference between the minimal heat production of the fed animal and the heat production of the fasting animal. The energy expended in, for example, the synthesis of pancreatic protein which is utilized in digestion would be considered a component of the heat increment (Baldwin 1968). The heat increment of food utilization varies with the composition of the diet and the level of feeding (Forbes et al 1931, Marston 1948). The energy expenditures associated with utilizing comparable amounts of carbohydrate, protein and fat are different (Brody 1945, Baldwin 1968, Milligan 1971).

In a warm environment, the heat increment is "wasted" energy that must be dissipated as heat. In a cold environment, this heat can be used to provide body heat. Brody (1945, p. 65) stated "Rubner found that the feeding of 320 g of meat to a dog at 7°C did not increase his heat production; but feeding 320 g of meat at an environmental temperature at 30°C increased his metabolism (above the post absorptive level) by 50 per cent". In the ruminant animal, the heat increment persists for about 3 to 4 days after a meal (Forbes et al 1926, 1927, 1931, Blaxter and Wainman 1966).

The heat increment, though an essential feature in the nutrition of the cow, is a "useful" energy expenditure only when she is in need

of additional body heat.

4. Pregnancy

There is good evidence that an increment of energy over maintenance is required for pregnancy. The Agricultural Research Council (ARC) (1965) in their review of energy requirements of ruminants state "heat production increases in late pregnancy at a rate which is greater than that which would be expected for a non-pregnant animal retaining the same amount of energy". In energy balance studies, Flatt et al (1969) found pregnant cows lost more of their gross energy intake as heat than did non-pregnant cows. During the last few days before parturition, total heat production in the cows rose rapidly. At a constant intake of food, heat production of pregnant ewes increased progressively throughout gestation to a level at term about 30 per cent greater than the expected value had the ewes not been pregnant (Graham 1964).

In a serial slaughter study conducted by Lodge and Heaney (1970), it was found that pregnant ewes utilized considerably more body energy reserves for maintenance than did non-pregnant ewes.

Blood analysis data from ewes also indicate additional energy is expended during pregnancy. Levels of FFA and ketone bodies in plasma were found to be higher in pregnant than in non-pregnant ewes (Karihaloo et al 1970). Increments of additional feed were required to prevent a rise in levels of plasma FFA and ketone bodies in ewes as pregnancy advanced (Reid and Hinks 1962a, Russel et al 1967b). Furthermore, it appears a direct relationship exists between the weight of the fetuses and the plasma levels of FFA and ketone bodies in ewes (Reid and Hinks 1962a, 1962b, Russel et al 1967a, Karihaloo et al 1970).

Precise quantitative data of the energy required for pregnancy are limited. Russel et al (1967b) estimated that about 400 Kcal per kg of fetus per day was the additional ME required to maintain a nutritional status in the pregnant ewe during the final 10 days of pregnancy. According to the data of Langlands and Sutherland (1968), the calculated daily increment of ME for pregnancy increased from 50 to 800 Kcal per ewe during the last 55 days of pregnancy. If expressed as per unit of fetus, it is about 180 Kcal per kg of fetus at term, which is a value less than half of the value determined by Russel et al (1967b) and is higher than the estimated value reported by Graham (1964). Graham (1964) found the ME used per kg of fetus was approximately 10 per cent of the ME requirement of the ewe herself. If this is applied to the ewes used by Langlands and Sutherland (1968), the energy requirement for pregnancy would be 120 Kcal per kg of fetus. The estimate of 800 Kcal per ewe for pregnancy was about 40 per cent of the total 2000 Kcal required for maintenance plus pregnancy for the ewes studied by Langlands and Sutherland (1968).

The energy expenditures for pregnancy in cows was calculated by ARC (1965) from the data of Jakobsen (1957) and indicates that 0.55 Mcal additional ME is expended per cow per day at 12 weeks prior to parturition and 2.4 Mcal per day at term. These values are somewhat lower than the mean values suggested by Flatt et al (1969), which were 3.7 to 5.0 Mcal ME per day per cow. It appears that energy expended for pregnancy in cows varies from 10 to 20 per cent of the total energy expended for maintenance of the pregnant cow. This proportion is not reached until near term.

5. Cold Stress

When the ambient temperature is below the critical temperature of an animal, additional energy must be expended to maintain body temperature (Kleiber 1961). The critical temperature of an animal is the ambient temperature at which an animal must increase heat production to maintain body temperature. The rate at which the additional energy is expended is dependent on the animal's ability to reduce the rate of heat loss from the body, that is the thermal insulation, and the animal's ability to generate additional heat. The loss of heat from the surface of an animal is directly proportional to the temperature gradient between this surface and the environment (Blaxter 1962).

Animals are able to some extent, to reduce heat loss by increasing the effective insulation of the surface tissues and the hair coat, and by changes in behaviour. This can be achieved without an additional expenditure of energy (Scholander et al 1950a, Irving 1956, Irving et al 1956) and, of course, it is more advantageous to the animal's energy balance to combat cold stress by an increase in insulation than for the animal to increase its heat production.

Additional heat production by steers in response to cold was measured by Blaxter and Wainman (1961a) using an indirect calorimeter technique. Heat production was minimal at ambient temperatures of 15 to 25°C, but increased significantly when the temperature was lowered to 5 or -5°C.

The physiological mechanisms of reducing heat loss and producing additional heat will be discussed in more detail in the following sections.

V. REDUCING HEAT LOSS DURING COLD STRESS

Reducing heat loss is part of an animal's ability to adapt to cold climates. Scholander et al (1950c) stated, "there are no signs so far that body temperature of mammals and birds is adaptive to the different climates on earth". Peripheral parts of an animal and some birds are capable of adapting to reduce heat loss by allowing the surface temperatures to approach ambient temperatures but not go below 0°C. Such observations were made on the bare skin of swine (Irving 1956); the extremities of aquatic birds, feral mammals (Scholander et al 1950a), ox (Whittow 1962) and sheep (Webster and Blaxter 1966). Allowing the surface tissue particularly on the extremities to cool via vasoconstriction (reduced blood flow) reduces the temperature gradient and consequently reduces the rate of heat loss. According to determinations by Whittow (1962), the surface of the extremities accounts for about one third of the total surface area of the ox.

Hayman and Nay (1961) indicate cattle adjust the external insulation (hair coat) during the various seasons by the growth or shedding of hair. In the spring, prior to warm summer, the heavy winter coat is shed and a new coat begins to grow. Maximum growth of the new coat is reached before the time of the colder winter climate implying that season and not temperature controls hair growth. It was found that exposure to cold had no effect on the growth rate of wool on sheep (Webster et al 1969) and the hair on cattle (Webster et al 1970) when compared to control animals kept indoors during winter.

Animals can also adjust their external insulation by piloerection of the hair when exposed to a cold climate (Blaxter and Wainman 1961, Blaxter and Wainman 1964). Piloerection increased the coat depth of

steers by 30 per cent (Blaxter and Wainman 1964). Scholander et al (1950a) found that lemming fur fluffed up to the maximum, provided roughly twice as much insulation as with the fur smoothed down.

In bare skinned animals such as the pig (Irving 1956, Irving et al 1956) and aquatic animals (Scholander et al 1950a), the subcutaneous fat and the surface tissue are the principal or only insulating material.

Behavioural adaptation can influence heat retention. Arctic animals with low external insulation will seek shelters and huddle close together. Dogs curl up to reduce their exposed surface area and thus reduce heat loss in a cold climate (Scholander et al 1950a, 1950c). It is commonly known that cattle will turn away from a cold wind and expose their hind quarter to the direct force of the wind. By exposing the hind quarter to the wind, it was shown the heat production of sheep was lower than by exposing a side (Joyce and Blaxter 1964). This has the effect of reducing the surface area exposed to the direct force of the wind. Wind reduces the insulation value of the external insulation composed of the hair or fleece plus the air interface (Blaxter and Wainman 1964, Joyce and Blaxter 1964b).

The amount of subcutaneous fat and depth of hair coat of cows are thus likely to affect their resistance to cold stress and thus their maintenance energy requirement.

VI. PRODUCTION OF ADDITIONAL HEAT DURING COLD STRESS

During periods of cold stress an animal can produce additional heat by gross muscular activity, shivering and/or by non-shivering thermogenesis. The energy expended in gross muscular activity,

discussed earlier results in a release of heat in the body (Brody 1945).

Shivering is another form of muscular activity but no external work is done by the body (Blaxter 1962). It may be defined as the rapid rhythmic contraction and relaxation of skeletal muscles.

Non-shivering thermogenesis is the production of heat without any muscular activity and so may be referred to as chemical heat production (Cottle and Carlson 1956, Heroux et al 1956).

Several authors have shown that additional heat is produced by gross muscular activity of movement as well as by shivering. Scholander et al (1950b) found that the small animals in cages in the Arctic, increased their heat production mainly by bursts of muscular metabolism. This was either as shivering or gross activity or both. The onset of shivering in marmots arousing from hibernation was marked by a rapid rise in rectal temperature (Smith and Hock 1963). A six day old calf exposed to cold by Jenkins et al (1968) resulted in shivering and an increase in oxygen consumption. Blaxter and Wainman (1964) observed shivering in steers in a cold environment particularly after the hair had been shorn off and noted that the visible shivering was not continuous but tended to increase with time after feeding. This suggests the heat production associated with feeding activity and the heat increment of food utilization replaced the heat produced by shivering. Shivering was observed to be very severe when cold water was consumed, suggesting that additional heat was required to warm the water and to maintain body temperature.

According to Jansky (1969), rats adapt to cold by increasing heat production via non-shivering thermogenesis but in larger species

adaptation by improving insulation is more effective. This is in agreement with Scholander et al (1950a) particularly for the Eskimo dogs and Arctic foxes. Air temperatures had no effect on FFA and ketone bodies and food intake of heavily fleeced sheep in an exceptionally cold winter at Edmonton, Alberta (Karihaloo et al 1970), indicating the critical temperature of these animals was below the environmental temperature because of the large body insulation value.

Non-shivering thermogenesis was studied by Heroux et al (1956) by transferring both cold acclimated rats and warm acclimated rats into an environment of 6°C. The temperature drops were less marked in the colon and leg muscles of cold acclimated rats. Furthermore, they observed increased electrical activity in muscles of the warm acclimated rats indicating that these animals were shivering. No change in the electrical activity in the muscles of the cold acclimated rats was observed suggesting these rats increased metabolism by non-shivering or chemical thermogenesis. These results are strongly supported by Cottle and Carlson (1956) who blocked the muscular activity in rats with curare and observed only cold acclimated rats could increase heat production sufficiently to maintain body temperatures as the test room was cooled.

Non-shivering thermogenesis was observed in new born lambs by Alexander and Williams (1968) and Jenkins and Thompson (1968) but it disappeared at an early age. No evidence of non-shivering thermogenesis was found in a 6 day old calf (Jenkins et al 1968) or in the new born pig (Le Blanc and Mount 1967). Increases in heat production by sheep (Webster et al 1969) and cattle (Webster et al 1970) kept exposed to outdoor cold were reported, but without mention of any shivering.

VII. CHANGES IN BLOOD CONSTITUENTS IN RESPONSE TO STRESS

Blood constituents can be used to reflect the effect of stressor agents (Wilson 1971).

A cold stimulus elicits an increase in thyroid activity associated with an increase in metabolism (Brown-Grant et al 1954, Lundgren and Johnson 1964, Smith and Hoijer 1962). The fact that thyroid hormone is essential to an animal for survival in the cold is well documented (Hsieh and Carlson 1957, Carlson 1960, Cottle 1960, Hock 1962, Smith and Hoijer 1962).

Cottle (1960) found that the thyroid was essential in developing acclimation to cold but not to maintain it. He cites Sellers and You (1950) as being able to maintain cold acclimated thyroidectomized rats indefinitely at 1.5°C when given a small daily dose of thyroxine. However, the metabolic response to cold is not directly dependent upon the amount of circulating thyroxin (Hsieh and Carlson 1957, Hock 1962). It was found low levels of thyroxin appear to be effective in stimulating metabolism in cold acclimated rats (Cottle 1960, Galton and Nisula 1969).

Protein bound iodine (PBI) levels in plasma and the disappearance of labelled iodine from the thyrcid of cows was studied by Yousef et al (1967). Increases in PBI levels at 1°C over the levels at 18°C were not evident until after 36 hours of cold stimulation. The levels increased until 84 hours and then decreased but did not return fully to the control level. Thyroid activity in rats reaches maximum activity with about 3 weeks exposure to cold and returns to near normal after 6 to 10 weeks (Cottle 1960). A 3 hour exposure to cold was observed to not increase the levels of plasma PBI in men (Wilson et al

1970).

These data suggest thyroxin increases the sensitivity to cold and that the sensitivity to cold can be maintained with low levels of thyroxin. The sensitized effect then makes it possible for cold acclimated animals to increase heat production by non-shivering thermogenesis during periods of cold stress (Hock 1962).

It is stated by Carlson (1960) and Hock (1962) that fatty acids are mobilized from adipose tissue by the synergetic action of thyroxin and catecholamines (epinephrine and norepinephrine). The catecholamines do not act directly but appear to stimulate adenyl cyclase which in turn stimulates lipase that brings about the hydrolysis of triglycerides (Hock 1962). The fatty acids are released in the blood plasma and are available for metabolism by the animal (Bowden 1971).

In liver mitochondria, in the presence of oxaloacetate, fatty acids are converted to intermediates of the TCA cycle or completely oxidized (Krebs 1966). In the absence of oxaloacetate, ketone bodies are formed. Whenever the concentration of glucose in plasma is low, the free fatty acids level in plasma rises (Reid and Hinks 1962c), which is roughly paralleled by an increase in the concentration of ketone bodies in the plasma (Krebs 1966). Ketones provide a third source of energy in addition to glucose and fatty acids (Krebs 1966).

Hematocrits have been found to increase upon acute cold exposure (Eliot et al 1949, Deb and Hart 1956, Hercus and Bowman 1959, Everett and Matson 1961, Mears and Groves 1969, Wilson et al 1970). Blood volumes concomitantly decreased 8 per cent while hematocrits increased 8 per cent in men exposed to cold for 3 hours (Wilson et al 1970). Whether the increased hematocrits in other experiments were associated

with hemoconcentration or as a response to increased oxygen required with increased metabolism was not indicated.

The above review indicates the present understanding of the energy requirements of pregnant beef cows has been largely based on studies made on cattle other than pregnant cows and on other species. Also evident from the review is the need for more information on the energy requirements of cows in different physiological states and when exposed to different environments.

EXPERIMENTAL

The main objectives of the present study were to determine the energy required to maintain mature pregnant beef cows, in different body conditions, under winter conditions in North Central Alberta. The influence of body condition on the animals' requirements as well as their physiological reactions to the stresses of winter were to be assessed.

DESIGN OF THE EXPERIMENT

The experiment was designed to have thirty pregnant cows in three different treatment groups representing different levels of body condition. At the start of the winter, the treatment groups were to be made up of twelve fat cows (F), six medium cows (M) and twelve cows in thin (T) body condition. Six cows from each group were to be fed to maintain their weight throughout the winter. The remaining six cows in each of the F and T groups were to be fed to maintain their weight until the onset of cold winter weather. At this time, the six fat cows would be switched to the ration offered the cows maintained in a thin body condition and would be termed the fat/thin (FT) group. At the same time, the six thin cows would be switched to the ration offered to the cows maintained in a fat body condition and termed the thin/fat (TF) group, thus anticipating one group of thin cows, the TF group, to gain weight and one group of fat cows, the FT group, to lose weight, during the remainder of the experiment. The design of the experiment is summarized in Figure 1.

Two additional cows in medium body condition were to be fed and managed the same as the M group throughout the experiment. These

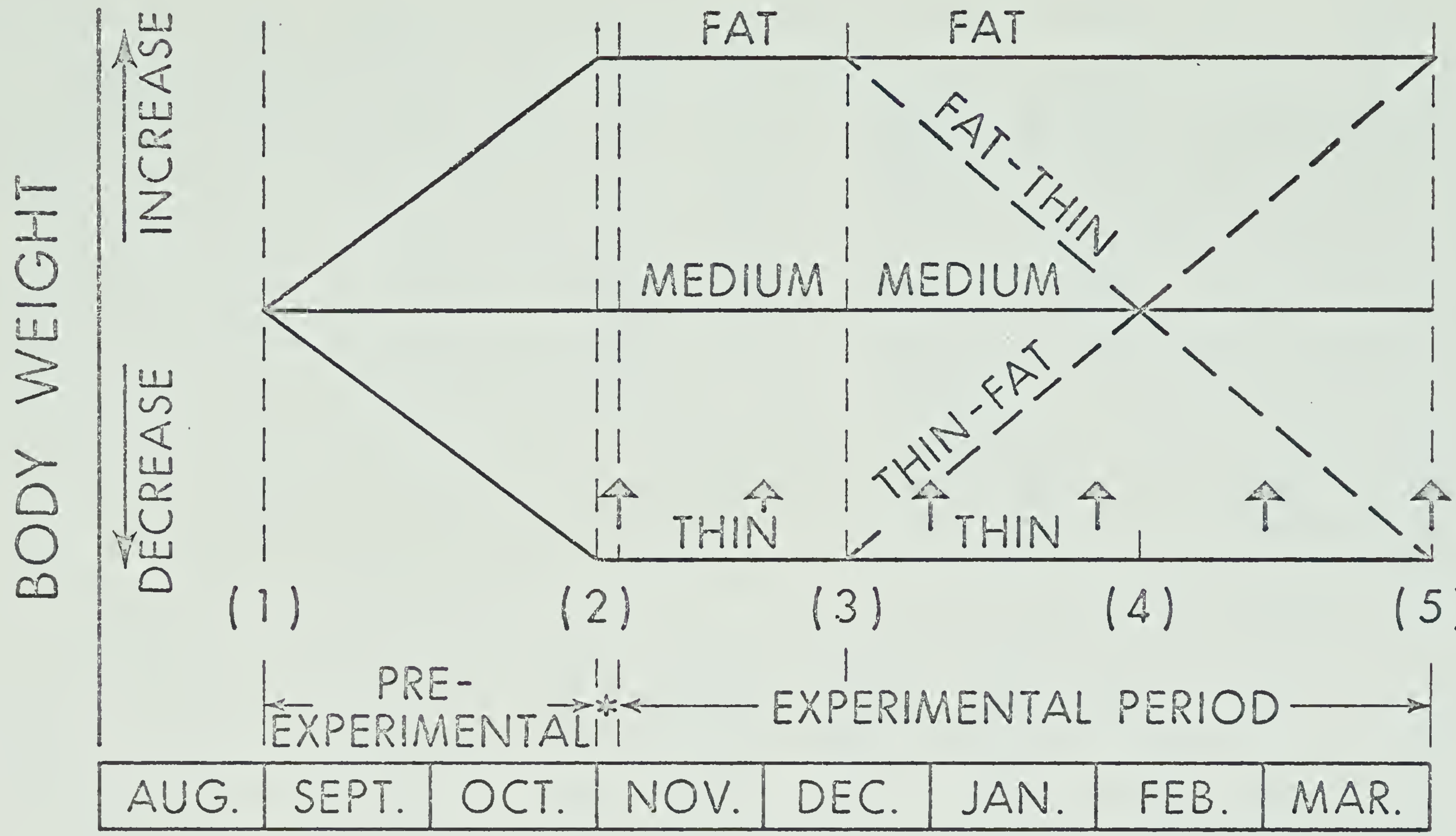

Figure 1. Design of the Experiment.

(1) Weaning of calves and initial allocation of groups.
(2) Skin and fat measured and final allocation of groups.
(3) Reallocation of groups to rations and onset of cold.
(4) Digestion trial.
(5) Termination of the experiment.
↑ Blood sampling times.
* Adjustment period for gut fill.

cows would be used as controls in the digestibility trial. (See DIGESTIBILITY TRIAL).

The rations were designed to provide adequate levels, based on NRC (1970) suggested requirements, of all nutrients except energy.

The following measurements were to be taken during the experiment:

Assessment Desired:	Measurement to be Taken:
1. Skeletal body size	- height at the withers
2. Maintenance energy requirement	- body weight, feed intake and digestibility of rations
3. Physiological adaptation to winter	- depth of hair coat, skin depth, subcutaneous fat depth and plasma protein bound iodine
4. Metabolic stress	- hematocrit and glucose, free fatty acid and ketone body levels in plasma
5. Climatic conditions	- ambient temperature, and daily run of wind.

The experiment was to start on November 1, 1970 and continue throughout the winter up to near the end of the gestation period. March 24 was set as the termination date of the experiment.

EXPERIMENTAL SITE AND FACILITIES

The experiment was conducted at the University of Alberta Ranch at Kinsella, Alberta. The fenced paddock in which the cows were kept was approximately two acres in size. Some wind and overhead shelter was provided by the small trees in and adjacent to the paddock. All forage in the paddock was removed by heavy grazing by non-experimental animals prior to the start of the experiment. A heated watering bowl connected to the underground water system was located in the paddock.

Thirty two outdoor individual feeding stalls (Figure 2) were situated on a concrete pad adjacent to the paddock. The cows were confined individually to the stalls by steel chains at the rear of the stalls.

A building adjacent to the feeding stalls was used for storing cut feed and housing the scale used to weigh the rations. A small enclosure within the paddock contained the meteorological recording equipment.

The scale for weighing the cows and the cattle squeeze for restraining the animals during blood sampling were located about 300 meters from the paddock.

ANIMALS AND THEIR MANAGEMENT

To achieve the prescribed conditions of the design an initial group of thirty-nine cows of similar liveweight and age were selected from the University of Alberta beef breeding herd (Berg 1971). These cows with calves at foot were taken off range on August 26, 1970. At this time the calves were weaned, and the cows were weighed and allocated to the three groups for adjustment of body condition.

During the pre-experimental period (Figure 1), fifteen cows allocated to the F group were kept in a feedlot pen. To achieve a fat body condition, they were offered, ad libitum, a ration of barley and a custom prepared protein, mineral, vitamin supplement, plus 1 kg of hay daily per cow. The cows in the medium group were kept on pasture to maintain a level of body condition near to that at the time the treatment groups were formed. The liveweights of the sixteen cows allocated to the thin group were reduced by offering a daily ration of only 4.5

Fig. 2. Feeding stalls at the experimental site.

kg of oat straw per cow. These cows were kept in a small feedlot during this period.

All the cows were pregnancy tested by a veterinarian in late October. Final selection and allocation of the experimental cows was made on November 1, after the cows were weighed, and skin depth and fat depth measurements were taken. Due to the number of non-pregnant cows, one non-pregnant and five pregnant cows were retained in each experimental group.

The thirty cows in the experimental groups ranged in age from four to six years. The breed composition consisted of crossbreds involving Angus, Brown Swiss, Charolais, Galloway or Herefords and hybrids involving Angus, Charolais, Galloway and Herefords (Berg 1971). Hair coat colors were variable. The liveweights of the cows ranged from 431 to 678 kg, with a mean of 530 kg at the time of initial selection on August 26, 1970. Some variation in body condition was evident.

From November 1, 1970 until March 24, 1971 all the experimental cows were managed as one herd. Each cow however, was offered her daily ration in an individual feeding stall and allowed approximately 2.5 hours (between 0800 hours and 1100 hours) to consume the ration. Bedding was not provided.

RATIONS

The experimental rations (Table 1) were formulated from chopped mixed grass hay, of fair to good quality for color and leafiness, rolled barley and a custom prepared protein supplement. Details of the supplement are shown in Table 2. The supplement was included in

the ration for the T group, to ensure an adequate level of digestible protein.

TABLE 1

Formulation of experimental rations

Ingredients	Thin kg	Medium kg	Fat kg
Hay	4.55	4.55	4.55
Barley	1.50	2.13	2.59
Supplement	0.14	-----	-----

A mineral-salt mixture was offered ad libitum as a 1:2 mixture of a calcium-phosphorus mineral (Electric Reduction Co. of Canada) and trace mineralized salt (Domtar Chemicals Ltd.) (Table 3). Supplemental Vitamins A, D and E were injected intramuscularly on December 16 and January 23. A 3 ml dose, containing 1,500,000 I.U. of Vitamin A; 225,000 I.U. of Vitamin D, and 150 I.U. of Vitamin E, was given each time. Water was available ad libitum except during the time of confinement for feeding and prior to the weekly weighing. (See MEASUREMENTS).

The feed components of the rations were analyzed for dry matter, gross energy, crude protein (N x 6.25), calcium and phosphorus. Dry matter digestibilities of the rations were determined by the chromium sesquioxide dilution technique. (See DIGESTIBILITY TRIAL). Metabolizable energy (ME) was calculated as 0.82 times the measured digestible energy (DE) values (NRC 1970).

TABLE 2

Formulation of custom prepared supplement

Ingredients	%
Barley, Ground	17.5
Urea	2.5
Rapeseed Meal	50.0
Dicalcium Phosphate	15.0
Sodium Tripolyphosphate	5.0
Salt, Trace Mineralized	10.0
	100.0

TABLE 3

Composition of mineral-salt mixture

	%
Salt	64.33
Calcium	6.17
Phosphorus	6.83
Fluorine	0.07
Ca. Iodate	0.01
Co. Oxide	0.004
Fe. Oxide	0.107
Cu. Oxide	0.022
Mn. Oxide	0.080
Zn. Oxide	0.267
Inert Carrier	22.11
	100.000

DIGESTIBILITY TRIAL

A digestibility trial was started 96 days after the start of the experiment (Figure 1) and continued for eight consecutive days to estimate the digestibilities of the rations. The thirty experimental cows each received 70 grams daily of shredded paper impregnated with chromic oxide. The chromic oxide paper, containing 37.87 per cent of Cr_2O_3, was mixed into the chopped hay portion of each cow's ration. The two additional non-experimental cows, treated the same as the medium group, were not given the chromic oxide paper, but samples of feces were taken as for the experimental cows. Feed samples for analysis were taken in triplicate during two days of the eight day digestibility trial. During the last four days of feeding chromic oxide, fecal samples were taken twice daily from the rectum of each cow. The daily sampling times were at the start and end of the feeding periods. Samples of similar size (approximately 10 grams) were taken by packing each fecal sample into a shallow 45 ml aluminum cup and levelling it off. These samples were placed inside polyethylene bags and frozen until the time of analysis. The samples from each cow were dried in a forced-draft oven at 70°C for 72 hours, then combined to make one composite four day sample for each cow. Each composite sample was finely ground using a Waring Blender and stored in a polyethylene bag. Dry matter of feed and feces was determined by the AOAC (1965) method. Gross energy in feed and feces was determined by means of a Parr oxygen bomb calorimeter.

Chromic oxide concentration in fecal samples was determined by a modified method of Hill and Anderson (1958) (See APPENDIX I).

MEASUREMENTS

1. Climatic Conditions

A cup anemometer was used to measure daily run of wind at a height of one meter. Total wind run and daily minimum and maximum temperatures were recorded each morning at feeding time. Daily mean temperatures were calculated as the mean of the maximum and minimum for the day. Degree days, as a measure of cold stress, were calculated by totalling the number of degrees the average daily temperature was below -15°C during a period and dividing by the number of days in the period. The value of -15°C was selected as it approximates the likely critical temperature of the type of animals in the experiment (Webster et al 1970).

2. Weight of Cows

During the experiment, the cows were weighed at weekly intervals in the morning before they received their daily ration and after they had been kept away from water overnight. The weights were taken as accurately as possible by recording the weight several times with the automatic printer on the scale when the animal was standing as still as possible. In addition, an objective assessment was made from the readings on the dial by the operator as to what the true weight should be. The scale was calibrated before and after each set of weighings.

3. Skeletal Body Size

To assess the skeletal body size, the height of each cow at the withers was measured to the nearest centimeter.

4. Hair Coat Depth

The mean depth of hair coat was determined by measuring the depth at twenty nine sites on each cow excluding the distal parts of the extremities. Measurements were made on December 4 and on February 24.

5. Depth of Skin and Subcutaneous Fat

The depth of skin and subcutaneous fat were measured at ten sites on each cow, using an ultrasonic probe (Krautkramer Ultrasonic Flaw Detector, type U.S.M. 2). Measurements were made on November 1, 1970 and again at the end of the experiment on March 25, 1971. The measurement sites were at the 11th and 12th rib area at 8, 15, and 32 cm from the dorsal medial line; on the loin at 8 cm from the dorsal medial line; and at 7 cm intervals down the rump and thigh beginning at 8 cm from the dorsal medial line. The mean skin and fat depth were derived from the average of the 10 sites measured.

6. Blood Constituents

Twenty ml of jugular blood were taken from each cow at intervals of four weeks throughout the experiment, commencing on November 6, 1970. The blood samples were taken in the morning immediately after the weighing and before the cows received any feed or water. The animals were restrained in a stock squeeze with a head gate. Heparinized vacuum tubes and 20 gauge Vacutainer needles were used to obtain the blood samples which took about one minute of restrained time per animal. Immediately following sampling, the packed cell volume (PCV) was determined and the samples centrifuged at 3000 rpm for twenty minutes to separate the plasma. The plasma was removed with pasteur pipettes and stored frozen in glass or plastic vials. The plasma

samples were analysed for the following:

i) Glucose - glucose concentrations (mg/100 ml plasma) were determined by using the Technicon Auto-Analyser, Method File N-2b.

ii) Free Fatty Acid - free fatty acid (FFA) concentrations (μ moles/ml of plasma) were determined by the colorimetric method of Mosinger (1965).

iii) Ketone Bodies - these were determined by the method of Baker and White (1960) with modifications (APPENDIX II). Total ketone body concentrations were expressed as acetone equivalent (mg/100 ml plasma).

iv) Protein Bound Iodine - the protein bound iodine (PBI) (μg/100 ml plasma) was determined by Hycel Cuvette PBI Determinations Method (Hycel Inc., Houston, Texas, 1967).

CALCULATIONS OF MAINTENANCE ENERGY REQUIREMENTS

Maintenauce energy requirements (MER), for this experiment assumed to be the amount of energy required to exactly maintain live weights, were estimated from the metabolizable energy (ME) intake adjusted for any gain or loss in weight. The adjustment was based on the value of 5.17 Mcal of ME for each kg of gain or loss in weight. The calorific value of 5.17 Mcal was derived from studies conducted on cows at the University of Alberta Ranch during the winter of 1969-70 (Young and Berg 1970).

In some instances, the changes in live weight of the cows were greater than could be accounted for by the dietary intake alone. In such instances, the calculated energy requirement was averaged over

the period of wide fluctuations to arrive at a mean daily requirement.

STATISTICAL ANALYSIS

Analyses of variance were performed using computer programs available from the University of Alberta Computing Center. Duncan's New Multiple Range Test (Steel and Torrie 1960) was used in comparison of means.

RESULTS

GENERAL

All the animals remained healthy throughout the experiment except one cow in the T group which had a severe nose bleed on February 10. This required a veterinarian's attention. The cow was kept in the sick barn overnight and returned to the herd the next morning in time for feeding. There appeared to be no other ill effects for she continued to eat her prescribed ration and behave normally throughout the remainder of the experiment.

On December 3 all the rations were increased by an additional 2 kg of hay. This upward adjustment was made during a period of cold weather and coincided with the re-allocation of the FT and TF groups. The rations remained at the adjusted levels for the remainder of the experiment.

Occasionally a few cows left part of their ration, but this was included in the subsequent feedings and all the ration was eaten. The feed loss by spillage was very small. It was estimated to be less than 0.5 kg per cow during the entire experiment.

The water bowl in the experimental area froze up in December, and so on December 23 and throughout the remainder of the experiment, the cows were provided with water in a stock water tank located about 200 meters from the paddock.

A notable feature of the cows was their desire to chew on wood in the paddock. All the trees had the bark and wood deeply peeled as high as the cows could reach (Figure 3). As well, stumps and fallen trees and the wood fencing were deeply gouged by the cows.

Birth weights of the calves produced by the cows following the

Fig. 3. Effect of wood chewing by cows.

completion of the experiment were not significantly different in the 5 groups of cows (Appendix Table A1).

The non pregnant cows in the M and F groups only showed standing heat during the experiment. The one cow in the FT group diagnosed as not pregnant, later proved to be pregnant.

During a period of Infectious Bovine Rhinotracheitis (I.B.R.) outbreak at the ranch feedlot, where the cows were normally weighed, the cows were weighed on a portable beam scale on January 6 and 13 only. The portable scale was calibrated against the scale normally used. There was no evidence of I.B.R. in the experimental cows.

CLIMATIC CONDITIONS DURING THE EXPERIMENT

Figure 4 shows the weekly means for temperature, wind speed, and degree days of cold stress. On examining the mean weekly temperatures, different periods of climatic conditions were evident. Thus, the experiment was divided into seven unequal climatic periods of 14 to 28 days in each, according to the prevailing climatic conditions (Table 4). Each period was judged to differ climatically from both the preceeding or the following one. Relatively mild weather in period I was followed by the onset of cold weather characterized by rapidly decreasing ambient temperatures in period II. Periods III and IV represent two rapid cycles from cold to mild to cold weather which was followed by continuous cold weather in period V. During period VI the temperatures were rapidly rising and then levelled off into relatively constant mild weather in period VII. The climatic conditions at the experimental site are summarized in Table 4.

Wind speeds at the site during each period (Figure 4) were low

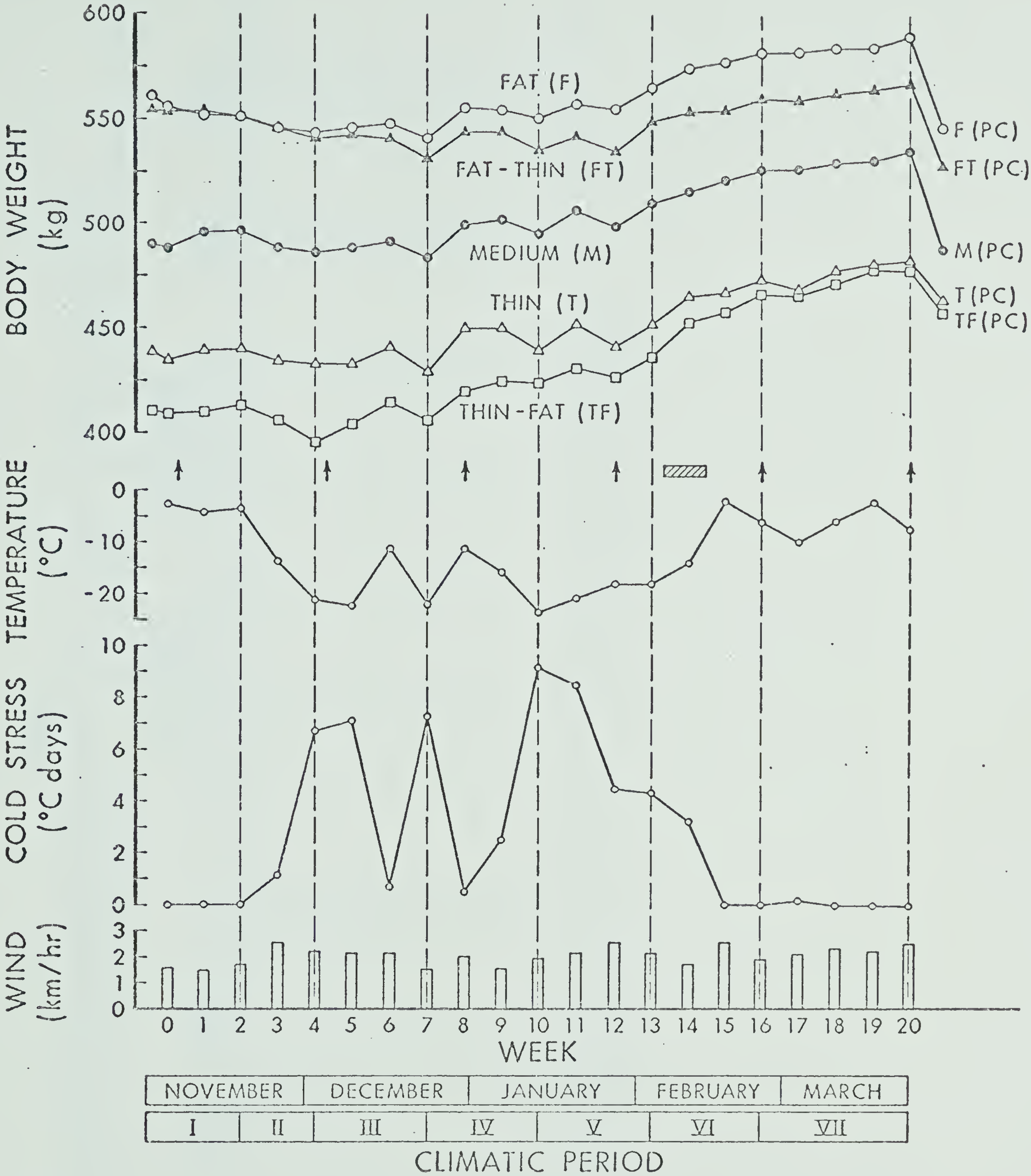

Figure 4. Weekly means of climatic conditions and liveweights of the cows by groups are plotted relative to week of the experiment, month of the year and climatic period. Time of blood sampling ↑ and the digestion trial ▨ are indicated. Cold stress was calculated as the total number of degrees the mean daily ambient temperature in a climatic period was below -15°C divided by the number of days in the period.

TABLE 4

Climatic conditions during experimental period, degree days of cold stress and ambient temperatures (°C).

Climatic Period	#	No. of Days	Degree C Days*	Mean Daily	Days of Maximum Temperature			Days of Minimum Temperature		Mean Minimum	Mean Maximum
					>0	0 to -15	<-15	0 to -15	<-15		
Nov. 1 - 18	I	18	0	- 3.36	6	12	0	18	0	- 6.0	- 0.7
Nov. 19 - Dec. 2	II	14	3.93	-17.42	1	8	5	3	11	-22.2	-12.6
Dec. 3 - 24	III	22	5.14	-18.37	2	12	8	3	19	-25.0	-11.2
Dec. 25 - Jan. 13	IV	20	4.28	-16.70	4	11	5	4	16	-22.4	- 9.5
Jan. 14 - Feb. 3	V	21	5.80	-18.80	4	8	9	2	19	-26.0	-11.6
Feb. 4 - 24	VI	21	1.08	- 7.09	11	10	0	15	6	-14.6	0.4
Feb. 25 - Mar. 24	VII	28	0.04	- 6.03	19	9	0	19	9	-14.0	7.7

* Mean daily number of degrees temperature was less than -15°C as an estimate of the amount of cold stress.

and with relatively little variation from day to day. These values were about 15 to 16 per cent of those recorded by the meteorological equipment situated approximately 300 meters away on top of a hill overlooking the surrounding area. Because of the low level of wind to which the cows were exposed, it will not be considered further.

WEIGHT OF COWS

There were significant ($P < 0.05$) differences in the mean initial weights of the five treatment groups (Table 5) indicating the pre-experimental adjustments were effective. The mean weekly weights and the mean weekly ambient temperatures plotted relative to time showed similar patterns during the experiment (Figure 4). That is, a decrease or increase in ambient temperature coincided with a decrease and increase respectively in the mean weekly weights of the cows.

The individual weekly weight changes during the experiment fluctuated widely in some weeks. Large negative changes in one week were offset by large positive changes in the adjacent week.

In general, the mean weekly weights in all groups appeared to remain relatively constant until late January when gains in all groups were apparent (Figure 4). The gains in weight were comparable in magnitude to the decrease in liveweight from the final weight to the post calving weight (Table 5). Calves were born during a period of 8 weeks following termination of the experiment. All calves and cows were weighed within about one day of calving.

A notable decrease in liveweight was evident in all groups on the regular weighing day of December 23. During the preceding week there was a severe decrease in temperature coincident with the water

TABLE 5

Means and standard deviations of height, weight and fat depth of cows and birth weight of calves

	Thin	Thin/Fat	Medium	Fat	Fat/Thin	All Groups
Withers Ht. (cm)	128 ± 3^{ab}	125 ± 2^{a}	124 ± 4^{a}	129 ± 4^{ac}	132 ± 6^{bc}	128 ± 2***
Cow Wt @ Wean*	537 ± 32^{a}	505 ± 57^{a}	534 ± 68^{a}	536 ± 38^{a}	545 ± 76^{a}	531 ± 23
Initial Wt Nov. 4 (kg)	434 ± 41^{ab}	408 ± 37^{a}	480 ± 67^{b}	556 ± 22^{c}	553 ± 55^{c}	486 ± 19
Final Wt March 24 (kg)	481 ± 35^{a}	476 ± 24^{a}	533 ± 61^{b}	588 ± 33^{c}	566 ± 41^{bc}	529 ± 17
Post Calving Wt** (kg)	464 ± 48^{a}	456 ± 33^{a}	487 ± 52^{ab}	546 ± 30^{b}	527 ± 70^{b}	496 ± 20
Fat Nov. 1 (mm)	3.43 ± 1.28^{a}	3.07 ± 0.99^{a}	4.45 ± 1.87^{ab}	5.47 ± 1.58^{b}	6.22 ± 1.72^{b}	4.53 ± 0.62
Fat March 25 (mm)	3.42 ± 1.30^{ab}	2.85 ± 0.97^{a}	5.00 ± 1.59^{bc}	5.17 ± 1.61^{c}	4.18 ± 0.95^{abc}	4.12 ± 0.54
Calf Birth Wt** (kg)	32 ± 16	34 ± 18	37 ± 19	34 ± 18	44 ± 9	36 ± 7

a - c values in the same row with the same letter are not significantly ($P < 0.05$) different.
* - At time of selection (August 1970).
** - Taken within one day after calving following termination of the experiment.
*** - Standard error.

bowl freezing so the cows were without water for probably two days prior to this weighing. The cows were provided water on that day then re-weighed for an official weight the following day on December 24, using the normal procedure. A large decrease in body weight was still evident (Figure 4).

SKELETAL BODY SIZE

The heights of the cows measured at the withers as an indication of skeletal body size (Jeffery and Berg, in press) showed a range from 116.8 to 142.9 centimeters. Significant ($P < 0.05$) differences were found between some groups (Table 5). This was mainly attributed to one cow in the FT group that was noticeably larger than the remainder of the herd. She was 15.4 cm higher at the withers than the mean of the other cows, and 5.8 cm higher than the next highest cow. She was noticeably broad and deep bodied and consistently had the highest weight of all the cows at all times. A summary of the withers' heights by groups is shown in Table 5.

DEPTH OF HAIR COAT

Hair coat depths measured on December 4 were greater than when measured on February 24. The mean depths were 12.96 and 11.00 mm respectively. There were not any significant differences between groups at either time of measuring.

It appeared that the hair was more erect (piloerection) on all cows on December 4 than on February 24. The temperature at the time of measuring was colder on December 4 than on February 24 and this was probably the reason for the piloerection (Blaxter and Wainman 1961, 1964).

DEPTH OF SKIN

Skin depth of all animals averaged 7.23 and 7.67 mm at the start and end respectively, of the experiment. Significant differences between treatment groups were not found in either set of measurements, nor did there tend to be any change in depth during the experiment.

DEPTH OF SUBCUTANEOUS FAT

Significant ($P < 0.05$) differences of fat depth were found between groups, both at the start and at the end of the experiment (Table 5). There were not any significant changes in fat depth within four of the groups during the experiment. The FT group did have a significant ($P < 0.01$) decrease in fat depth during the experiment.

BLOOD CONSTITUENTS

(i) Packed Cell Volume (PCV)

There was a tendency for the PCV of the blood from the cows in the T, TF and M groups to remain relatively constant throughout the experiment (Table 6). The cows in the FT and F group tended to have their PCV values decline during the experiment. The mean values of the five groups were more widely separated initially (36.2 to 44.9 per cent) and tended to gradually approach a common value (39 per cent) by the end of the experiment.

A two-way analysis of variance indicated a low level of significance ($P < 0.05$) between groups, but a highly significant effect between climatic periods (Appendix Table A1). The significant differences between groups were in climatic periods I, III and IV (Table 6).

The non-pregnant cow in each group tended to have PCV values

TABLE 6

Means and standard deviations of packed cell volume (% of blood) of cows in each group and climatic period.

Climatic Period	Thin	Thin/Fat	Medium	Fat	Fat/Thin	All Groups
I	38.6 ± 4.2^{a}	36.2 ± 3.7^{a}	40.1 ± 2.2^{ab}	43.1 ± 2.2^{bc}	44.9 ± 3.9^{c}	$40.6 \pm 1.4^{*}$
II						
III	35.7 ± 4.6^{ab}	33.9 ± 2.2^{a}	39.0 ± 3.6^{bc}	42.7 ± 3.6^{cd}	43.6 ± 3.6^{d}	39.0 ± 1.5
IV	37.2 ± 4.9^{ab}	36.1 ± 1.5^{a}	40.4 ± 3.9^{ac}	41.2 ± 2.4^{bc}	43.7 ± 4.8^{c}	39.7 ± 1.5
V	38.1 ± 3.7^{a}	38.8 ± 1.6^{a}	40.8 ± 4.2^{a}	39.8 ± 3.8^{a}	42.7 ± 5.3^{a}	40.0 ± 1.6
VI	36.2 ± 3.9^{a}	36.8 ± 1.8^{a}	38.1 ± 3.9^{a}	36.9 ± 3.6^{a}	39.5 ± 3.0^{a}	37.5 ± 1.4
VII	38.0 ± 5.0^{a}	38.5 ± 1.9^{a}	39.0 ± 4.7^{a}	39.0 ± 3.5^{a}	40.2 ± 3.3^{a}	38.9 ± 1.6
Group Mean	37.3	36.7	39.6	40.4	42.4	39.3

a - d values in a row with the same letter are not significantly ($P < 0.05$) different.
* - Standard error.

above the average for the group.

(ii) Glucose Concentrations

Plasma glucose concentrations tended to gradually decrease throughout the experiment (Table 7). Significant ($P < 0.05$) differences between groups were present in the initial sampling (Period I). The value for the FT group in climatic period III showed the only other significant ($P < 0.05$) difference. This larger value at that time was mostly due to the results from one cow which was extremely excited at the time of sampling. All groups showed an increase in plasma glucose in period III and thereafter a general decline except for a slight increase from climatic period VI to period VII. A two-way analysis of variance showed the differences between climatic periods to be highly significant ($P < 0.005$) (Appendix Table A1).

The mean concentrations of plasma glucose in the pregnant cows declined more rapidly than in the cows that were not pregnant.

(iii) Free Fatty Acid (FFA) Concentrations

The concentration of FFA in plasma (Table 8) tended to increase throughout the winter. The most rapid and consistent increase was in the cows in the FT group. The mean concentrations for this group in climatic period VII was significantly ($P < 0.05$) greater than all other groups. Highly significant ($P < 0.005$) differences were indicated (Appendix Table A1) between groups and between climatic periods by two-way analysis of variance. There was not any significant difference between the cows in the F and T groups.

In climatic periods VI and VII, the non pregnant cows had a lower mean concentration of FFA in plasma than did those that were pregnant.

TABLE 7

Means and standard deviations of glucose concentrations (mg/100 ml plasma) of cows in each group and climatic period.

Climatic Period	Thin	Thin/Fat	Medium	Fat	Fat/Thin	All Groups
I	75 ± 5^{ab}	72 ± 3^{a}	78 ± 6^{ac}	83 ± 6^{bc}	85 ± 9^{c}	$79 \pm 2.5^{*}$
II						
III	78 ± 5^{a}	78 ± 7^{a}	82 ± 6^{a}	85 ± 6^{a}	95 ± 14	84 ± 3
IV	73 ± 6^{a}	75 ± 4^{a}	75 ± 7^{a}	79 ± 5^{a}	78 ± 5^{a}	76 ± 2
V	74 ± 6^{a}	74 ± 3^{a}	74 ± 5^{a}	79 ± 5^{a}	76 ± 5^{a}	76 ± 2
VI	68 ± 5^{a}	70 ± 3^{a}	71 ± 7^{a}	72 ± 8^{a}	74 ± 6^{a}	71 ± 2
VII	69 ± 7^{a}	69 ± 4^{a}	73 ± 11^{a}	75 ± 10^{a}	77 ± 9^{a}	73 ± 3
Group Mean	73	73	75	79	81	76

a - c values in a row with the same letter are not significantly ($P < 0.05$) different.
* - Standard error.

TABLE 8

Means and standard deviations of free fatty acids concentrations (μ moles/ml plasma) of cows in each group and climatic period.

Climatic Period	Thin	Thin/Fat	Medium	Fat	Fat/Thin	All Groups
I	1.30 ± 0.24^{ac}	0.91 ± 0.29^{a}	0.95 ± 0.26^{ab}	1.33 ± 0.47^{bc}	1.43 ± 0.27^{c}	$1.18 \pm 0.13^{*}$
II						
III	1.49 ± 0.24^{a}	1.33 ± 0.32^{a}	1.32 ± 0.40^{a}	1.50 ± 0.32^{a}	1.58 ± 0.52^{a}	1.44 ± 0.15
IV	1.22 ± 0.30^{bc}	0.81 ± 0.22^{a}	0.93 ± 0.27^{ab}	1.14 ± 0.31^{b}	1.50 ± 0.17^{c}	1.12 ± 0.11
V	1.54 ± 0.46^{bc}	0.89 ± 0.45^{a}	1.22 ± 0.31^{ab}	1.49 ± 0.39^{bc}	1.84 ± 0.25^{c}	1.39 ± 0.16
VI	1.47 ± 0.48^{bc}	0.96 ± 0.16^{a}	1.11 ± 0.17^{ab}	1.75 ± 0.68^{cd}	1.93 ± 0.26^{d}	1.44 ± 0.16
VII	1.80 ± 0.27^{a}	1.35 ± 0.34^{a}	1.78 ± 0.32^{a}	1.82 ± 0.27^{a}	2.42 ± 0.70	1.83 ± 0.17
Group Mean	1.47	1.04	1.22	1.50	1.78	1.40

a - d values in rows with the same letter are not significantly ($P<0.05$) different.
* - Standard error.

(iv) Ketone Body Concentrations

The pattern of the concentrations of ketone bodies in plasma, relative to time, was similar in all groups (Table 9). The cows in the FT group showed the highest concentrations in all climatic periods. All groups showed increases in climatic period VII over period VI when the climate was mild in both periods. Only in climatic period VI were the greater concentrations of ketone bodies in plasma of the cows in F group significantly ($P < 0.05$) greater than those in the T group. The level of significance ($P < 0.025$) due to treatment groups was low, but very high due to climatic periods. (Appendix Table A1).

There was not any difference between pregnant and non-pregnant cows until climatic period VII, when the concentrations were much greater in the pregnant than in the non-pregnant cows.

(v) Protein Bound Iodine (PBI) Concentrations

The concentrations of PBI in plasma of all the cows, except those in the TF group tended to have large increases from climatic periods I to III with the onset of the cold weather after which the PBI values tended to remain at a constant level. However, there was an increase again in climatic period VII (Table 10). There were not any significant differences between groups. The differences between climatic periods were highly significant ($P < 0.005$) (Appendix Table A1).

There did not appear to be any differences between pregnant and non-pregnant cows.

DRY MATTER DIGESTIBILITY AND METABOLIZABLE ENERGY (ME) INTAKE

The cows on the average digested 61.4 per cent of the dry matter intake. There were not any significant differences between the five

TABLE 9

Means and standard deviations of ketone body concentrations (mg/100 ml plasma) of cows in each group and climatic period.

Climatic Period	Thin	Thin/Fat	Medium	Fat	Fat/Thin	All Groups
I	1.49 ± 0.17^{ab}	1.77 ± 0.37^{bc}	1.26 ± 0.33^{a}	1.73 ± 0.27^{bc}	2.04 ± 0.60^{c}	$1.66 \pm 0.15^{*}$
II						
III	1.96 ± 0.41^{a}	2.04 ± 0.24^{a}	1.98 ± 0.29^{a}	2.06 ± 0.52^{a}	2.56 ± 0.91^{a}	2.12 ± 0.22
IV	0.79 ± 0.60^{a}	0.88 ± 0.75^{a}	0.93 ± 0.38^{a}	1.24 ± 0.75^{ab}	1.71 ± 0.44^{b}	1.11 ± 0.25
V	2.09 ± 0.44^{ac}	1.93 ± 0.32^{ab}	1.83 ± 0.42^{a}	2.17 ± 0.77^{ad}	2.47 ± 0.28^{bcd}	2.10 ± 0.19
VI	0.88 ± 0.51^{a}	0.63 ± 0.29^{a}	0.79 ± 0.45^{a}	1.79 ± 0.87^{b}	1.75 ± 0.37^{b}	1.17 ± 0.22
VII	3.82 ± 2.05^{ac}	2.70 ± 0.79^{a}	3.67 ± 1.23^{ab}	4.28 ± 2.81^{ad}	5.52 ± 2.85^{bcd}	4.00 ± 0.86
Group Mean	1.84	1.66	1.74	2.21	2.67	2.02

a - d values in a row with the same letter are not significantly ($P < 0.05$) different.
* - Standard error.

TABLE 10

Means and standard deviations of protein bound iodine concentrations (ug/100 ml plasma) of cows in each group and climatic period.

Climatic Period	Thin	Thin/Fat	Medium	Fat	Fat/Thin	All Groups
I	2.40 ± 0.44^{a}	3.04 ± 2.27^{a}	2.23 ± 0.51^{a}	2.33 ± 0.39^{a}	2.28 ± 0.44^{a}	$2.45 \pm 1.04^{*}$
II						
III	3.05 ± 0.43^{a}	3.03 ± 0.46^{a}	3.30 ± 0.46^{a}	3.29 ± 0.43^{a}	2.86 ± 0.26^{a}	3.11 ± 0.17
IV	2.93 ± 0.61^{a}	3.08 ± 0.33^{a}	3.35 ± 0.39^{a}	3.08 ± 0.44^{a}	3.30 ± 0.74^{a}	3.15 ± 0.51
V	3.08 ± 0.75^{a}	3.14 ± 0.99^{a}	3.61 ± 0.70^{a}	3.68 ± 0.64^{a}	3.12 ± 0.89^{a}	3.33 ± 0.33
VI	3.01 ± 0.35^{a}	3.10 ± 0.58^{a}	3.32 ± 0.29^{a}	3.52 ± 0.34^{a}	3.17 ± 0.33^{a}	3.22 ± 0.16
VII	3.21 ± 0.75^{a}	3.88 ± 0.51^{a}	3.68 ± 0.67^{a}	3.74 ± 0.63^{a}	3.62 ± 0.49^{a}	3.63 ± 0.25
Group Mean	2.95	3.21	3.25	3.27	3.06	3.15

a - d values in a row with the same letter are not significantly ($P < 0.05$) different.
* - Standard error.

groups. The standard error of the mean was ±1.02 per cent.

The ME intakes were calculated from the DE for each cow before pooling the results. Table 11 shows the mean ME intake of each group during each climatic period. There were not any differences between groups on the same ration. The ME intake for each group during November 1 to December 2 was calculated using the mean dry matter digestibility of the groups on the particular ration during the digestion trial.

TABLE 11

Metabolizable energy intakes (Mcal/cow/24 hr) of cows in each group and climatic period

Climatic Period	Thin	Thin/Fat	Medium	Fat	Fat/Thin
I - II	11.8	11.8	13.3	14.5	14.5
III - VII	16.2	19.0	18.0	19.2	16.2

MAINTENANCE ENERGY REQUIREMENTS

The requirements of metabolizable energy (ME) for maintenance by the cows in the five treatment groups during each period are summarized in Table 12. A two-way analysis of variance showed the differences in requirements to be highly significant ($P < 0.005$) both between groups and between periods, with only a low level of significance for the interaction term. (Appendix Table A1).

The maintenance energy requirement was significantly ($P < 0.05$) greater for cows in the F group than in the T group, except during climatic periods II and V. The cows in the TF group tended to have

TABLE 12

Means and standard deviations of maintenance energy requirements (Mcal ME/cow/24 hr) of cows in each group and climatic period.

Climatic Period	Thin	Thin/Fat	Medium	Fat	Fat/Thin	All Groups
I	10.3 ± 2.3^{a}	11.4 ± 1.7^{ab}	11.1 ± 2.0^{a}	17.3 ± 2.9^{c}	15.1 ± 4.6^{bc}	$13.0 \pm 1.2^{*}$
II	14.9 ± 3.2^{a}	16.1 ± 2.5^{a}	19.1 ± 1.4^{a}	17.3 ± 4.8^{a}	19.3 ± 1.2^{a}	17.3 ± 1.2
III	12.5 ± 2.1^{a}	14.9 ± 3.2^{ac}	13.2 ± 1.6^{ab}	16.6 ± 1.2^{c}	15.2 ± 1.6^{bc}	14.5 ± 0.8
IV	15.5 ± 2.3^{a}	16.9 ± 1.0^{ac}	17.6 ± 1.9^{bcd}	19.2 ± 1.3^{d}	16.8 ± 1.2^{ab}	17.2 ± 0.7
V	14.6 ± 1.8^{a}	16.2 ± 2.3^{a}	15.4 ± 2.4^{a}	15.7 ± 2.0^{a}	13.7 ± 1.9^{a}	15.1 ± 0.8
VI	11.1 ± 2.2^{a}	11.8 ± 2.3^{a}	13.3 ± 1.0^{ab}	15.0 ± 2.0^{bc}	13.7 ± 3.2^{ac}	13.0 ± 0.9
VII	14.5 ± 1.5^{a}	17.2 ± 1.1^{b}	15.7 ± 1.7^{a}	17.7 ± 0.8^{b}	14.8 ± 1.0^{a}	16.0 ± 0.5
Group Mean	13.4	14.9	15.0	17.0	15.5	15.1

a - d values in a row with the same letter are not significantly ($P < 0.05$) different.
* - Standard error.

higher requirements than those in the T group, but the difference was significant ($P < 0.05$) in climatic period VII only. Conversely the cows in the FT group tended to have a lower requirement of ME for maintenance than those in the F group, but the differences were significant ($P < 0.05$) in climatic periods IV and VII only.

The energy required for maintenance by the non-pregnant cow in each group did not tend to differ from the mean of all the cows in the group.

DISCUSSION

The interpretation of the results obtained for estimates of the energy required for maintenance of the cows depends on the reliance that can be placed on the measurements of metabolizable energy (ME) intakes, the liveweights and the estimate of the calorific value of each unit of gain or loss in body weight.

The reliance that can be placed on the ME intake values will be considered first. These measurements are based on the daily weighed rations and the estimates of digestibility.

Most authors tend to agree the chromic oxide dilution technique provides lower estimates of ration digestibility than the total collection method. But as stated by Troelsen (1965), the accuracy can be improved if the time of day selected for sampling is when the mean concentrations of chromic oxide in the feces are closest to 100 per cent recovery of chromic oxide administered and the standard deviations of the estimates are small.

The results reported by Hoogendoorn and Grieve (1969) indicated the dry matter digestion coefficients, obtained by using the chromic oxide dilution technique, were in close agreement with the values from the total collection method when fecal samples were taken at or near the time of administering the chromic oxide. This observation is supported by the results reported by Troelsen (1965) who fed long hay to sheep. Corbett et al (1960) thoroughly tested the use of shredded paper impregnated with Cr_2O_3 and were able to recover an average of 100.7 per cent of the fed chromic oxide during a period from two to eight days after initiating daily doses.

In the present trial, the administering of the chromic oxide

impregnated paper and sampling of the feces was done at feeding time. The number of animals used in the trial was much larger than those used by Corbett et al (1960), Troelsen (1965) and Hoogendoorn and Grieve (1969). Thus, it seems reasonable to believe the apparent digestibility values obtained from the digestibility trial were reliable.

The gravimetric method used to dispense the daily rations to each cow was precise and unlikely to contribute significantly to the variance of the results.

Weekly weight measurements of the cows were considered one of the largest sources of variation in the estimates of the maintenance energy requirements. Large negative and positive changes in weight occasionally found with some cows were at times difficult to interpret. As particular care was taken in the use and calibration of the scales, it is considered unlikely that major variations arose from errors in weighing or from the scales.

Graham (1969) suggested body weight changes in sheep cannot be measured accurately over short periods of two to three weeks. Other authors (Garrett et al 1959, Holmes and Lambourne 1970) believed weight change measurements on cattle over short terms are not reliable because of variations in gut fill and chemical composition of gained tissue. Averaging the weight changes over short intervals of wide fluctuations may have slightly biased the estimates of the change in weight of the cows as a response to climatic changes. This would have the effect of reducing the estimates of energy required for maintenance when the ambient temperature decreased rapidly and increasing the estimates when the temperature increased rapidly. This

is because the physiological reactions of the cows to sudden changes in ambient temperature affects body water flux (Bass and Henschel 1956). The relationship between body water flux and changes in ambient temperature will be discussed later.

The value of 5.17 Mcal of ME required or lost per kg of gain or loss in weight of the cows was derived using cows of similar breeding, type and age and from the same herd as the cows used in the present study. The value however, was derived (Young and Berg 1970) during the winter period prior to the present study and was based on estimates of feed intake and body weight change. No attempt was made by Young and Berg to measure the caloric content of the actual tissue gains or losses. As discussed in the review of literature, the value reported by Young and Berg (1970) for the calorific value for each unit of weight change, compares favorably with values for growing heifers but not fattening heifers (Garrett 1970). A large deviation from the value derived for cows is likely to occur only when substantial amounts of body fat are mobilized or deposited by the animal. Though there may be discrepancies as mentioned above, the value of 5.17 Mcal per kg of gain or loss in body weight was the best estimate available at this time for pregnant cows being fed at or near a maintenance level.

A well documented explanation for the wood chewing by the cows, which was observed throughout the experiment, is not available. Wood chewing by livestock is commonly associated with a dietary phosphorus deficiency (Church 1971). Blaxter et al (1961) and Campling and Balch (1961) suggest that ruminants attempt to eat to obtain a constant rumino-reticulum distention. The cows in the present experiment had

a calculated intake of phosphorus far in excess of the requirements listed by NRC (1970). After the cows had consumed their daily ration they behaved as though they were wanting more to eat. Thus, the wood chewing was attributed to the cows' attempt to overcome insufficient gut fill from the ration to distend the rumino-reticulum to cause satiety.

BODY WEIGHT CHANGES OVER WINTER

There were gains in body weight by the cows in all groups during the experimental period. Only in the Thin (T) and Thin/Fat (TF) groups, were the apparent gains in weight actually maternal tissue gains since the post calving weights, taken after the experiment was completed, were higher than their initial weights at the start of the experiment (Table 5). The Fat (F) and Medium (M) groups had mean post calving weights similar to their initial weights. Thus, the gains in weight were apparently due to the weight of the conceptus. Lodge and Heaney (1970) observed that pregnancy accounted for the gains in weight of pregnant ewes on the same level of feed intake as non pregnant ewes which lost weight. Actually, the pregnant ewes lost maternal tissue, late in pregnancy, in excess of the tissue losses by the non-pregnant ewes. Losses of maternal tissue by cows in the Fat/Thin (FT) group was evident when the post calving and initial weights were compared (Table 5).

The greatest short term gains and losses in weight by all groups coincided with large increases and decreases respectively in ambient temperature (see Figure 4). The changes in weight may be due to synthesis or catabolism of body tissue or changes in body water

retention. It has been known for a long time that exposure to cold can result in diuresis (Bass and Henschel 1956). Men exposed to several hours of cold, increased their urine output (Eliot et al 1949; Wilson et al 1970) and made compensatory decreases in output when they were returned to a warm environment (Wilson et al 1970). Except for the initial losses when first exposed, total body water does not change in rats exposed to cold for long periods of time (Bass and Henschel 1956). If tissue catabolism and synthesis were the only factors involved in weight changes, the extent of the changes in weight, observed in the cows on some occasions, would consist of daily losses of energy as great as 16.8 Mcal or gains as great as 18.5 Mcal of ME. Such gains in energy could not be accounted for by the levels of feed intake, especially after energy required for maintenance is taken into account. Thus, the rapid negative and positive weight changes that were observed in the present experiment were probably largely due to the short term change in body water content and not solely to changes in carcass tissue weight.

MAINTENANCE ENERGY REQUIREMENTS

The estimated metabolizable energy (ME) requirements per $kg^{3/4}$ of cows in each group in each climatic period are summarized in Table 13. The F group tended to have higher requirements but the differences were not significant.

Table 14 shows that energy requirements for maintenance increased with increasing weight but the requirements per unit of body weight or $kg^{3/4}$ were similar. These values are in agreement with the values of 123 to 151 $Kcal/kg^{3/4}/24$ hr calculated from the data reported by Flatt

TABLE 13

Means and standard deviations of energy required (Kcal ME/$kg^{3/4}$/24 hr) to maintain cows of different body conditions at a constant weight in each climatic period.

Climatic Period	Thin	Thin/Fat	Medium	Fat	Fat/Thin	All Groups
I	107.3 ± 20.5^{a}	125.0 ± 19.9^{ab}	107.2 ± 13.8^{a}	152.0 ± 27.9^{bc}	133.8 ± 42.4^{ac}	$125.1 \pm 10.9^{*}$
II	157.2 ± 35.8^{a}	179.3 ± 38.4^{a}	188.0 ± 24.7^{a}	152.7 ± 42.5^{a}	171.5 ± 10.0^{a}	169.7 ± 13.3
III	131.0 ± 17.8^{a}	164.5 ± 33.9^{b}	130.7 ± 21.9^{a}	147.5 ± 13.7^{ab}	136.3 ± 7.3^{a}	142.0 ± 8.5
IV	161.7 ± 24.1^{a}	183.5 ± 15.9^{a}	170.7 ± 21.1^{a}	168.7 ± 12.2^{a}	151.2 ± 18.3^{a}	167.1 ± 7.7
V	151.5 ± 23.3^{bc}	171.3 ± 20.7^{c}	147.3 ± 26.7^{ac}	137.5 ± 22.0^{ab}	122.7 ± 16.0^{a}	146.1 ± 9.0
VI	111.0 ± 20.9^{a}	120.3 ± 22.0^{a}	123.3 ± 8.7^{a}	128.5 ± 22.3^{a}	119.8 ± 25.2^{a}	120.6 ± 8.4
VII	143.0 ± 17.3^{ab}	169.7 ± 9.8	143.5 ± 19.3^{a}	149.3 ± 7.1^{b}	128.3 ± 11.7^{a}	146.8 ± 5.6

a - c values in a row with the same letter are not significantly ($P<0.05$) different.
* - Standard error.

TABLE 14

Metabolizable energy required daily to maintain cows of different body condition and weight

Treatment	Body Weight*	Daily ME Requirement*		
Group	(Kg)	Mcal/cow	Kcal/kg	Kcal/kg$^{3/4}$
Fat	560	16.9	30.2	147
Medium	498	14.4	28.8	137
Thin	449	13.1	29.1	134
Fat/Thin	547	14.9	27.2	132
Thin/Fat	431	14.7	34.1	156

* Mean over all climatic periods.

et al (1969) for cows in the last 2 to 3 months of pregnancy. Brody's (1945) formula of estimated digestible energy requirements for maintenance is calculated as twice the basal requirement of cows which would be approximately 140 Kcal of DE/kg$^{3/4}$ daily. This is calculated to be equivalent to 114.8 Kcal ME/kg$^{3/4}$ daily, which is very near the value of 116 Kcal of ME/kg$^{3/4}$/24 hr determined by Garrett (1970) for non pregnant animals.

The TF group had significantly ($P < 0.05$) higher requirements for maintenance than the other groups of cows in climatic period VII (Table 13). This is likely due to the fact the TF cows were storing energy at a higher rate than the cows in the other groups. The value of 5.17 Mcal per kg of body weight change as discussed above, probably was an underestimation, which resulted in a calculated higher requirement for maintenance. Graham (1969) found the net efficiency of ME utilization at a given level of energy retention, relative to maintenance, was the same for fat and thin sheep. Thus, a value between 5.17 and 6.33 Mcal of ME per kg of gain or loss of body weight may be applicable for cows retaining or losing energy at the level of the TF or FT groups.

The energy required for maintenance per kg$^{3/4}$ plotted relative to cold stress indicates the T group of cows were more responsive to cold (Figure 5). These cows increased their energy requirement directly with increasing cold stress whereas the mean requirement for the F group remained relatively constant over all levels of increasing cold stress. Both groups appeared to have lower requirements during late winter (decreasing cold stress) than they did initially for a similar amount of cold stress. Although the number of observations available

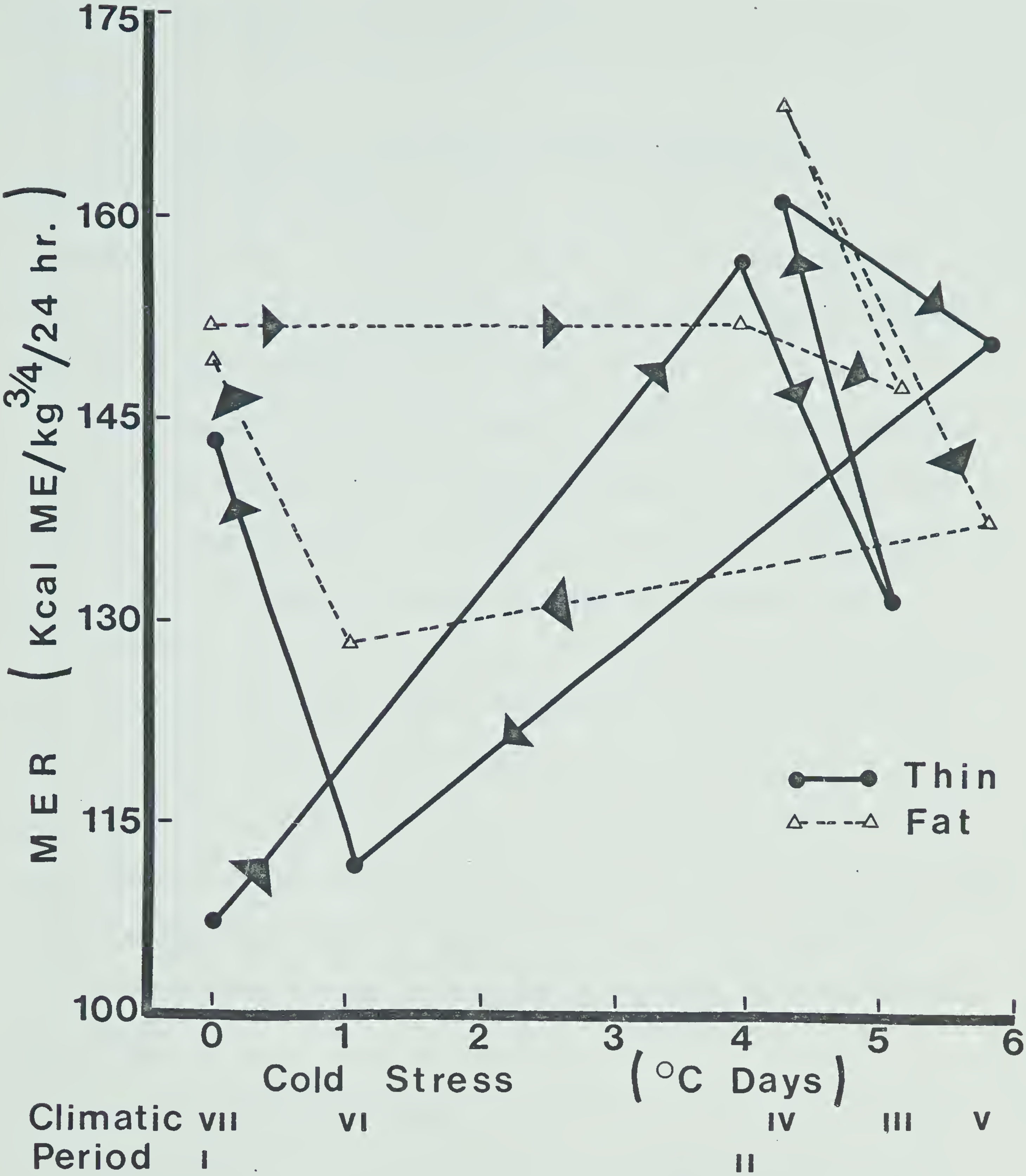

Figure 5. Mean daily maintenance energy requirement per cow, of cows in fat and thin body condition plotted relative to cold stress and climatic period.

limits the confidence in such an assessment, the trend is clearly evident.

There appears not to be a well founded explanation for the marked increases in maintenance energy requirements for all groups in climatic period IV. A likely explanation could be that the dehydration effect due to the water bowl freezing required more time to overcome than the present estimates would suggest.

The increased requirements during climatic period VII appear to be associated with the cost of pregnancy during the late stages of gestation. However, the small number of non pregnant cows tended to have similar increases. Flatt et al (1969) found cows in late pregnancy lost about 10 per cent more of their gross energy intake as heat than did non pregnant cows. Their report indicates the daily energy cost of pregnancy in the last 2 to 3 months of gestation is in the range of 8 to 38 Kcal of ME per $kg^{3/4}$ of the cows weight. This would amount to about 2.5 Mcal of ME daily per cow for the cows in the present experiment. This is about the extent of the increase in energy requirement during climatic period VII when the cold stress was absent.

ADAPTATION TO COLD BY BEEF COWS

The decrease in the depth of hair coat during the winter was attributed to piloerection in response to the colder climate at the time of measuring in December than in February. The cold stress during the December day was apparently great enough to elicit the response in the cows to increase their hair coat insulation. Similar responses have been reported by Blaxter and Wainman (1964) and

Scholander et al (1950a). In February, the prevailing climate on the day of measurement apparently did not constitute a cold stress.

The results of this experiment did not show an apparent adaptation by changes in depth of skin, which remained unchanged during winter.

The loss of subcutaneous fat by all the cows in the FT group indicates fat was mobilized to meet their energy requirements. This is also indicated by the fact they had the highest free fatty acid (FFA) levels in plasma of all groups in all periods (Table 8). Though there were not any significant changes in fat depth in the other four groups, there were wide positive and negative changes by some individuals within groups.

Adaptation to cold was reflected by the marked increase in protein bound iodine (PBI) concentration levels in plasma coincident with the onset of cold weather during climatic periods II and III (Figure 6). Thyroid secretion is considered essential in adaptation to cold and apparently acts by increasing the ability of the animal to produce heat (Cottle 1960). Hsieh and Carlson (1957) found that the heat production in rats progressively decreased with time following thyroidectomy. Thyroxin is necessary to bring about the calorigenic effect of the catecholamines in cold adaptation (Carlson 1960, Smith and Hoijer 1962). PBI levels in cattle were found to increase progressively up to 84 hours after sudden exposure to a temperature of 1°C and then decreased but were found not to return to the original pretreatment level (Yousef et al 1967). The results from the present experiment show the PBI levels increased curvilinearly relative to time (Figure 6). There was not any indication of a

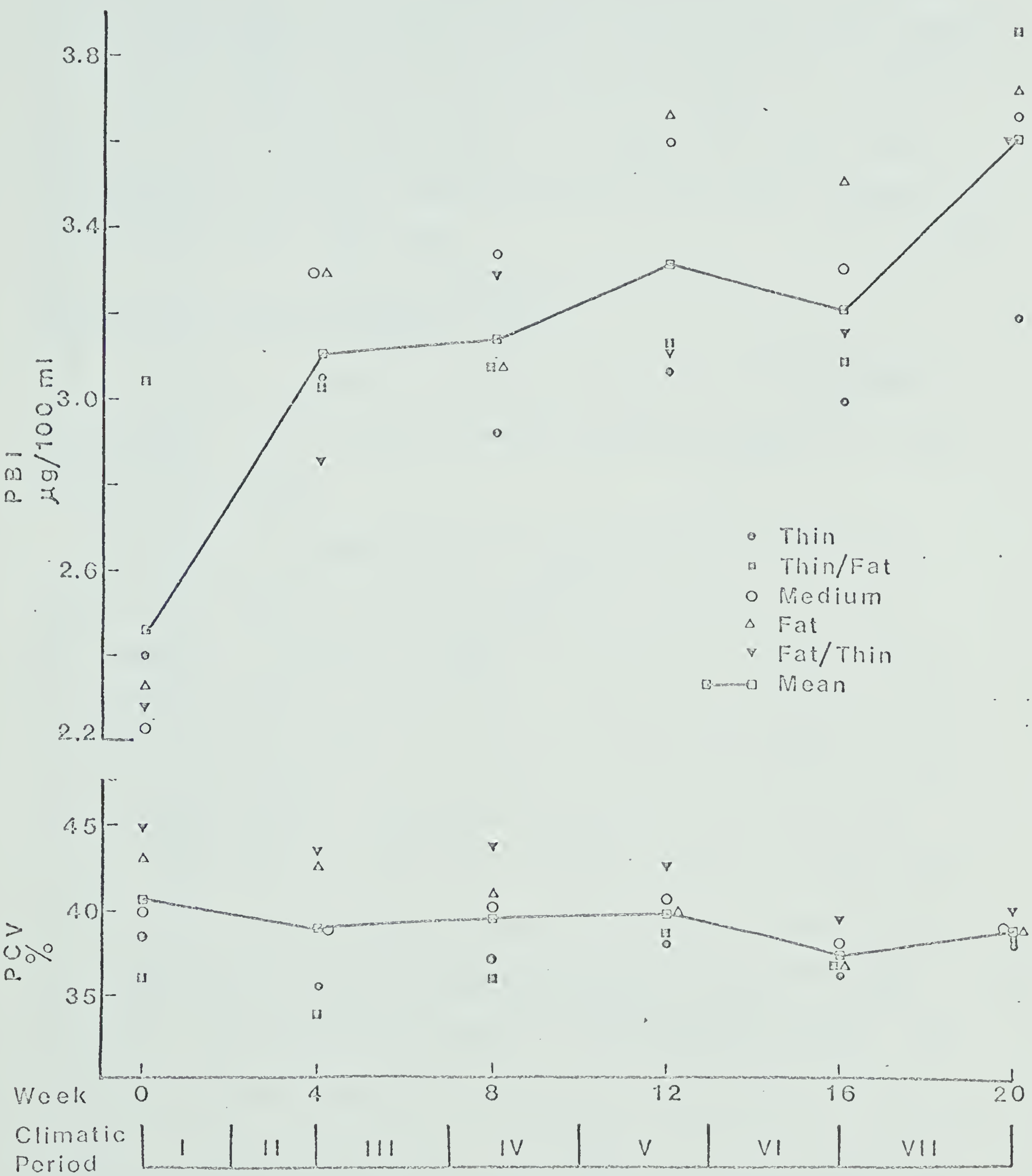

Figure 6. Overall mean and group means of protein bound iodine (PBI) and packed cell volume (PCV) plotted relative to weeks of the experiment and climatic periods.

decrease after a period of adaptation indicated by Cottle (1960) and Yousef et al (1967). The PBI levels plotted relative to the amount of cold stress show a continuous increase with increasing cold stress but do not decrease when cold stress decreases (Figure 7). This is likely due to the increasing demand for energy in the later stages of pregnancy (Graham 1964, ARC 1965, Russel et al 1967b, Langlands and Sutherland 1968, Hock 1962).

INDICATION OF METABOLIC STRESS IN COWS

The results obtained by measuring various blood constituents indicate that there was not any severe undernourishment of the cows during the experiment.

The values for glucose, FFA and ketone levels in plasma if considered as indices of energy metabolism in climatic period IV are difficult to interpret in view of the results of weight change and climatic conditions. The climatic conditions indicated the cold stress was only slightly less than in the adjacent climatic periods. The maintenance energy requirements increased during this period and yet the metabolic indices show a marked decrease in energy metabolism. It is possible that the level of stress for period IV was not reflected by the blood indices because the sampling of blood took place some time after the cows had been severely stressed, and sufficient time had elapsed for the measured blood constituents to return to a non-stressed level. The weights of the cows were taken more frequently than the blood samples, and thus reflected the stress.

The packed cell volume (PCV) values tended to decrease throughout the present study. The highest values obtained were at the initial

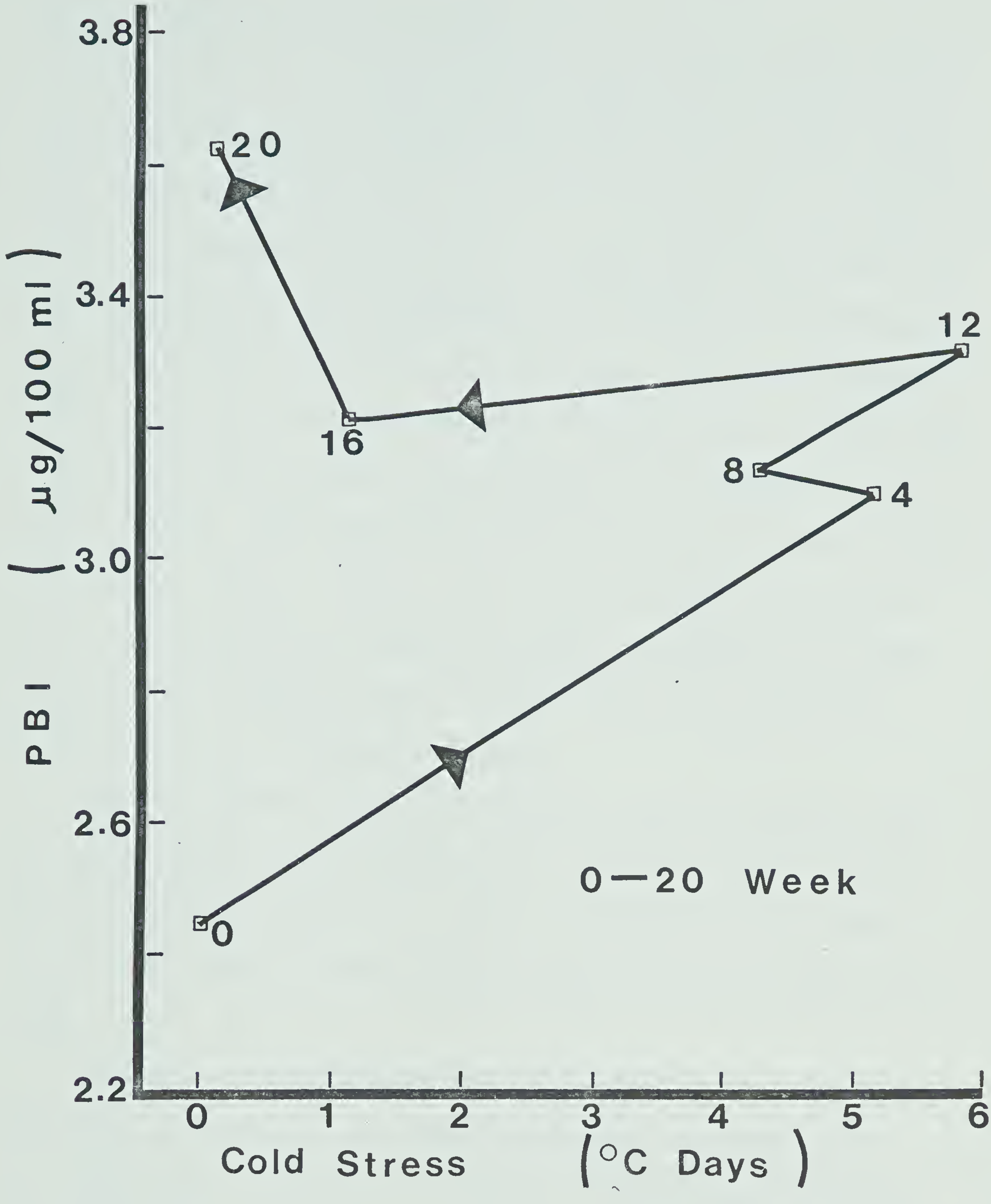

Figure 7. Mean protein bound iodine (PBI) of all cows at various times (weeks) of the experiment plotted relative to cold stress.

sampling (Figure 6) when the cold stress was determined to be zero. In other studies (e.g. Eliot et al 1949, Deb and Hart 1956, Hercus and Bowman 1959, Spur and Barlow 1959, Mears and Groves 1969, Wilson et al 1970) PCV concentrations were found to increase with exposure to cold. It would appear the variation in PCV values in the cows determined during the present experiment are a consequence of disturbances at bleeding times rather than of cold stress. Holmes and Lambourne (1970) found mild excitement resulted in increased PCV. It was also observed that the cows were more listless in cold weather than in milder weather. This was evident particularly with the cows with the lower body condition. Thus, it seems the cows became accustomed to the surroundings and the sampling procedure, resulting in a slight decline in PCV values in the F, FT and M groups and a relatively constant level in the T and TF groups.

Plasma glucose concentrations showed a general decrease during the experimental period accompanied by a general increase in plasma FFA concentrations (Figure 8). This is in support of the results obtained with sheep by Reid and Hinks (1962b, 1962c) and Adler et al (1963).

The glucose values obtained were higher than those reported by Radloff et al (1966) for dry cows, and by Adler et al (1963) for lactating cows. The values were similar to those found in ewes by Karihaloo et al (1970) who measured increased levels of plasma glucose in ewes during periods of intense cold. The increases of glucose in ewes were similar to the increases observed in period III of the present study when the cold stress was increasing.

Glucose utilization and FFA utilization is related to their

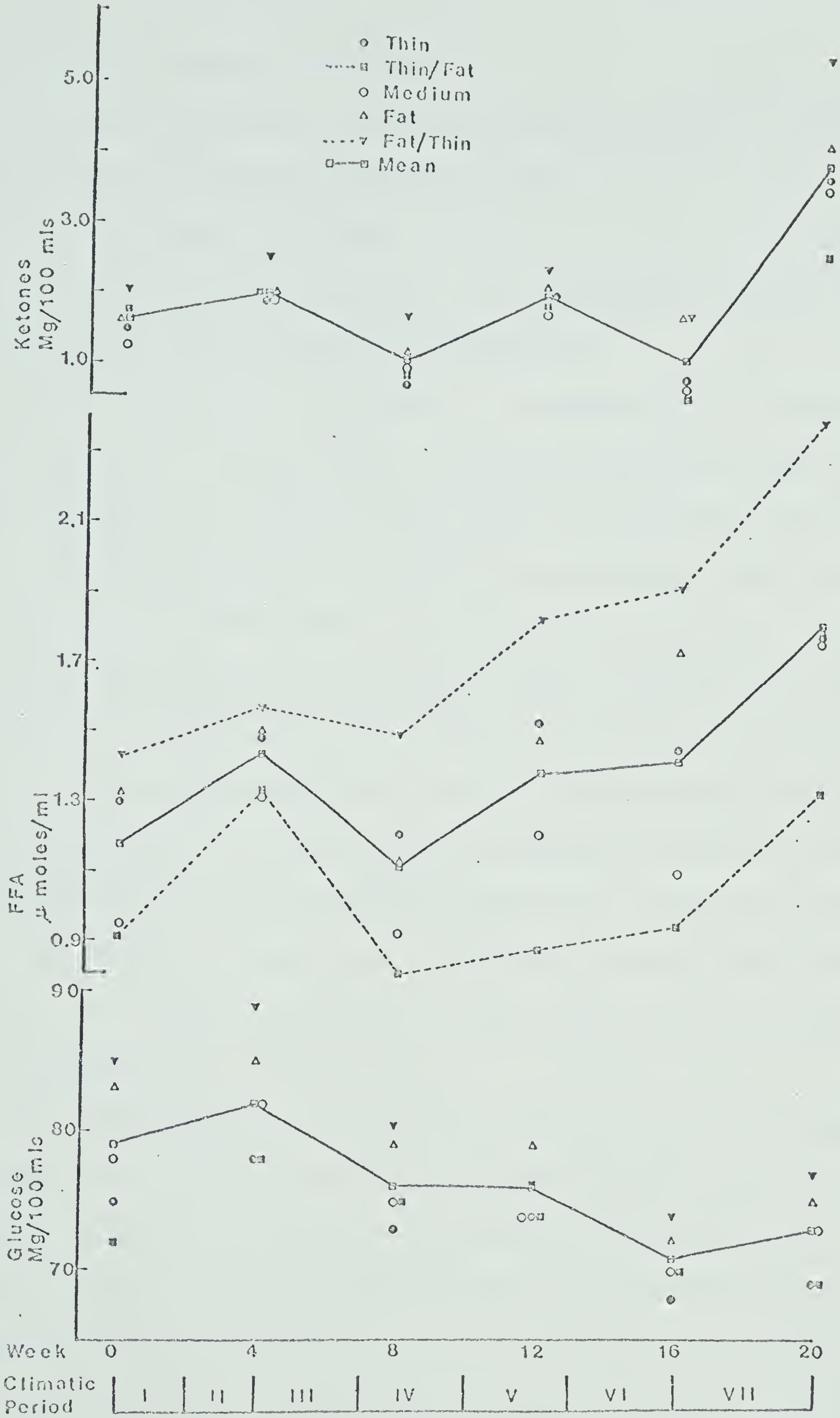

Figure 8. Overall mean and group means of glucose, free fatty acids (FFA) and ketones plotted relative to weeks of the experiment and climatic periods.

concentration in plasma (Reid 1969). The inverse relationship evident in the present study between these two metabolites makes it appear as though glucose utilization was being partially replaced by FFA utilization throughout the winter. It would also appear that depot fat was being mobilized as a result of the calorigenic effect of thyroxin after cold adaptation was established.

The FFA levels were comparatively the highest in the FT group and lowest in the TF group (Figure 8), in all climatic periods. It is likely the TF group on the increased ration, was obtaining its energy supply almost solely from rumen fermentation products. The FT group of cows had to mobilize depot fat to meet their requirements. Increased mobilization of fat was evident during fasting (Annison 1960, Karihaloo et al 1970) and during pregnancy of undernourished ewes (Reid and Hinks 1962b, Russel et al 1967a). The increased level of FFA concentration in climatic period VII (Figure 8) coincided with an increase in the PBI concentration (Figure 6). The FFA concentrations found in this experiment were comparable to those reported by Karihaloo et al (1970) for sheep but higher than others reported in the literature.

The concentrations of ketone bodies found in the present study were well within the range but below the mean value of 4.9 per cent reported by Adler et al (1963) for normal lactating cows, and at levels similar to those maintained by Reid and Hinks (1962b) in pregnant sheep to prevent ketosis.

The substantial increase in ketone levels in climatic period VII (Figure 8) is likely associated with pregnancy. The non pregnant cows were consistently below the average of their group in this period.

High levels of ketone body concentrations in late pregnancy of ewes were reported by Russel et al (1967a) and Karihaloo et al (1970). Since glucose and FFA levels were also elevated at this time, it indicates gluconeogenesis was taking place, restricting the oxidation of FFA, which resulted in the formation of ketone bodies (Krebs 1966).

The results of the present study suggest that metabolites in blood may be more sensitive indicators of undernourishment of pregnant beef cows in times of stress than are body weight changes. The intervals between blood sampling were not short enough to be conclusive in this. The levels of blood metabolites to use as guides in maintaining a nutritional status in pregnant beef cows have not been well defined.

When considering wintering feed costs, the results of the present study indicate it would be most economical to provide a level of energy for a herd of cows, of comparable body size, according to the requirements of the cows with the least body condition. Maintaining cows in a fat condition requires more total energy than to allow them to lose body condition by feeding at a lower level. The level of ketone bodies, in the fat cows mobilizing depot fat, to meet their energy requirements, did not appear to constitute a metabolic stress. Gardner (1969a) indicates it is not desirable to have cows build up body stores of energy, while they are dry and then mobilize it during lactation. He also states there is a greater response in milk production to extra feed fed during lactation if the cow is in a lowered body condition at parturition. Cows on low pre-partum and high post-partum energy levels display as good reproductive phenomena as cows maintained on high pre-partum and high post-partum energy levels (Wiltbank et al 1962, Wiltbank et al 1964).

CONCLUSIONS

The objective of this study was to determine the energy required to maintain body weights of beef cows in different body conditions, and to assess the effects of body condition on these requirements over winter. The energy required for maintenance is directly related to body weight and the level of cold stress. Cows of comparable skeletal body size, but, in fat body condition, have higher energy requirements for maintenance than cows in thin body condition. This can be attributed to the energy cost of maintaining greater tissue mass in the fat cows. The energy requirements per unit of metabolic weight are similar for cows in all body conditions.

Thin cows have greater increases in energy requirements than fat cows during periods of cold stress. However, the absolute energy requirements of the thin cows do not exceed the energy requirements of the fat cows, even in the cold weather. Fat cows offered feed at a level of intake sufficient to maintain the weight of thinner cows, utilize body tissue to meet their energy requirements.

The levels of free fatty acids in plasma can be used as an index of moderate metabolic stress of pregnant beef cows during winter. Cows in a negative energy balance, but showing a gain in weight due to pregnancy, can be utilizing body tissue to meet their energy requirements, as indicated by elevated levels of plasma free fatty acids. Cows gaining maternal tissue characteristically have low levels of plasma free fatty acids.

Under practical conditions, a saving in winter feed can be realized, if cows enter winter in a fat body condition, and allowed to draw on body energy reserves. In this way cows of comparable skeletal

body size will approach a common level of energy required for maintenance. Thus the minimum level of dietary energy intake required, is determined by the weight of the cows when they are at their minimum desirable level of body condition.

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APPENDIX I

PROCEDURE FOR THE DETERMINATION OF Cr_2O_3 IN FECES

Ref: Czarnocki, J., I. R. Sibbald and E. V. Evans, 1961. The determination of chromic oxide in samples of feed and excreta by acid digestion and spectrophotometry. Can. J. Anim. Sci. 41: 167-179.

Hill, F. W. and D. L. Anderson, 1958. Comparison of metabolizable energy and productive energy determinations with growing chicks. J. Nutr. 64: 587-603.

Reagents and Equipment

1. Concentrated nitric acid.
2. Concentrated sulfuric acid.
3. Digestion Mixture: dissolve 10 g sodium molybdate in 150 ml of water. Place the container in an ice bath and slowly add 150 ml of concentrated sulfuric acid. After cooling add 200 ml of 70% perchloric acid with stirring.
4. 100 ml Kjeldahl flasks calibrated to 110 ml.
5. Micro-Kjeldahl digestion unit.
6. Spectronic "20".

Procedure

1. Weigh sample, containing approximately 10 mg Cr_2O_3, wrap in filter paper and transfer to 100 ml Kjeldahl flask.
2. Add 10 ml concentrated nitric acid and allow to stand overnight (preferably on a steam bath).
3. Heat to dryness on micro-Kjeldahl digestion unit without charring.
4. Add 15 ml of digestion mixture and digest over low heat until white fumes appear. Digest over high heat until green color changes to yellow, orange or red (depending on chromium concentration). Heat for an additional 5 minutes following color change.
5. Remove flask and allow to stand at room temperature to cool for handling.
6. Add 60 ml of distilled water, then 20 ml of concentrated sulfuric acid and bring flask contents to volume (110 ml) with distilled water.

7. Cool to room temperature, and bring up to volume.

8. Seal flasks and allow to stand overnight to precipitate inorganic material.

9. Read optical density at 450 mμ.

APPENDIX II

PROCEDURE FOR THE DETERMINATION OF KETONE BODIES IN PLASMA

Ref: Baker, N. and R. White. 1957. Simplified micromethod for the calorimetric determination of total acetone bodies in blood. N.Z. J. Sci. and Technol. 38: 1001-1008, also in Chem. Abstr. 54: 14345 (1960).

Reagents and Equipment

1. 11.7 N H_2SO_4.
2. 0.34% $K_2Cr_2O_7$.
3. 7.6 N NaOH.
4. Alcoholic salicylaldehyde - 20% vol/vol in 95% ethanol.
5. An acetone standard containing 0.01 mg/ml in a dark bottle and stored in a refrigerator.
6. Silicone grease or teflon thread tape (obtainable from a plumbing supply house).
7. Heating bath containing glycerine, or a drying oven at 110-120°C. The heating bath requires about 3 liters of glycerine.
8. 19 x 150 mm Kimax tubes with teflon lined screw caps.
9. Small tubes approximately 60 x 8 mm.
10. Spectronic "20".
11. Protein-free blood filtrate solutions:

    5% Zinc sulfate
    0.3 N Barium Hydroxide

When titrated against each other these two reagents must be of equal molar concentration. The final pH of the solution in plasma should be slightly acidic, approximately pH 6.5, to obtain a clear filtrate.

Procedure

1. Prepare a protein-free blood filtrate. Measure 1 ml of plasma and 4 ml of distilled water into a test tube. Mix, add 2.5 ml $Ba(OH)_2$ mix, then add 2.5 ml zinc sulfate, mix, then centrifuge for approximately 10 minutes at about 2000 to 3000 rpm.

2. Measure 1 ml 11.7 N H_2SO_4 into large test tubes.

3. Add 2 ml protein-free blood filtrate and 2 ml water.

4. Measure 1 ml of 0.34% $K_2Cr_2O_7$ into small tubes and lower one carefully into each of the large tubes so as to keep the solutions separated.

5. Cover the threaded portion of the Kimax tubes with silicone grease or teflon tape, then turn on the screw caps and tighten firmly to obtain a perfect seal.

6. Heat the tubes for 10 minutes in the drying oven (or glycerine bath) at 110-120°C. Do not overheat, as some of the tubes or caps are liable to fracture from excess pressure.

7. Remove the tubes from the oven (or bath), invert them to mix the solution. Thoroughly mix by inverting and shaking several times. Reheat for 30 minutes at 110-120°C.

8. Prepare a set of standards with 0, 0.01, 0.02 and 0.03 mg of acetone in tubes containing 4, 3, 2 and 1 ml of H_2O respectively plus 1 ml of 11.7 N H_2SO_4 and 1 ml of 0.34% $K_2Cr_2O_7$. Mix by swirling but do not heat in the oven (or bath).

Color Development

1. To the unknown, standards and blanks add 6.0 ml of 7.6 N NaOH and mix thoroughly.

2. Add 1 ml of alcoholic salicylaldehyde and cap all the tubes and quickly mix thoroughly, using a vortex mixer.

3. Heat in a water bath at 45-50°C for 40 minutes.

4. Allow the tubes and solutions to cool for 40 minutes to develop the color and read at 490 mμ.

APPENDIX TABLE A1

Two-way analysis of variance F values

Variable	Group	Period	Group/Period
MER	14.29**	19.41**	2.17**
Weight	11.26**	140.84**	5.92**
PCV	3.26*	8.95**	3.81**
Glucose	2.38	40.05**	2.08**
FFA	9.10**	20.26**	1.24
Ketones	3.86*	40.67**	0.95
PBI	0.82	11.43**	0.76

* $P < 0.05$, ** $P < 0.01$.

One-way analysis of variance F values

Variable	Group	Variable	Group
Withers Height	3.22*	Skin Depth (Nov.)	0.26
Cow Wt. @ Weaning	0.44	Skin Depth (Mar.)	1.43
Initial Weight	12.11**	Fat Depth (Nov.)	4.59**
Final Weight	9.16**	Fat Depth (Mar.)	3.45*
Post Calving Wt.	3.82*	% D.M. Digestibility	2.42
Hair Coat (Dec.)	0.43	ME Intake	17.57**
Hair Coat (Feb.)	1.67	Calf Birth Wt.	0.43

* $P < 0.05$, ** $P < 0.01$.